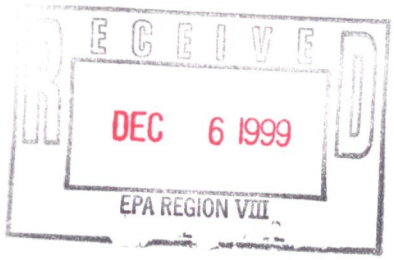
Harding Lawson Associates



HLA

01514VIC-V

December 3, 1999

42708

Ms. Valois Shea
U.S. EPA Region VIII
Underground Injection Control 8P2-W-GW
999 18th Street
Suite 500
Denver, Colorado 80202-2466

Additional Information for Evaluation of Underground Injection Control
CDOT Region 6 Headquarters
2000 South Holly Street
Denver, Colorado

Dear Ms. Shea:

On behalf of the Colorado Department of Transportation (CDOT), Harding Lawson Associates (HLA) is providing additional information to the U.S. EPA Underground Injection Control (UIC) program for a remediation system at the CDOT Region 6 Headquarters site. The information provided consists of a Bioremediation Treatability Study performed by HLA.

Should you have any questions regarding the information presented or require additional information, please contact me at (303) 293-6156.

Sincerely,

HARDING LAWSON ASSOCIATES

Paul H. Weaverling
Senior Geologist
Project Manager

PHW/jkw
EPA_UICInfoA.doc/JKW

Attachments: Attachment A – Appendix E Bioremediation Treatability Study

cc: Theresa Santangelo-Dreiling – CDOT
CDOT Project file

Final Interim Measures Report
Colorado Department of Transportation
Region 6 Headquarters Facility
Denver, Colorado

Prepared for:

Colorado Department of Transportation
Region 6
2000 South Holly Street
Denver, Colorado 80222

HLA Project No. 42708 12.6

October 22, 1999

Harding Lawson Associates
Engineering and Environmental Services
707 Seventeenth Street, Suite 2400
Denver, Colorado 80202 (303) 292 5365

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Appendix E

BIOREMEDIATION TREATABILITY STUDY

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FIGURE

BACKGROUND

A treatability study was performed by HLA to evaluate the potential effectiveness of enhanced aerobic biodegradation for treatment of dissolved phase VOCs at the Colorado Department of Transportation Region 6 Headquarters (Site). The objectives of the biodegradation treatability study were to:

- Perform a microbial evaluation of the groundwater and soil samples to assess the presence of methylene chloride degraders;
- Develop a nutrient profile to assess existing concentrations of nutrients in the soil and groundwater samples;
- Perform a biostimulation test on groundwater and soil samples to evaluate the rate of removal of methylene chloride concentrations under aerobic conditions.

Initially, the biostimulation test included three groups: an undiluted test group and a diluted test group to evaluate the potential for toxic inhibition to the microbial population at high concentrations of methylene chloride, and a killed control test group. The control was incubated under the same laboratory conditions and accounted for non-biological removal of methylene chloride during the testing period. The biostimulation test was modified to include an anaerobic test group to address the issue of the occurrence of faculatative methylene chloride degrading microorganisms on the basis of correspondence from William Mahaffey (Pelorus) to Brian Laflamme (HLA) dated March 15, 1999. Faculatative microorganisms are those which may grow in the presence or absence of oxygen and are common in situations when a VOC (in this case, methylene chloride) is utilized by the microorganism as a primary substrate for food and energy. Thus, the resulting biostimulation test was composed of four groups: high test aerobic, diluted test aerobic, high test anaerobic, and killed control.

samples are summarized in Table 1, and are at the low end of a range acceptable for enhancement of biological degradation. Microorganisms capable of degrading methylene chloride as a primary source of carbon and energy were enumerated using the Most Probable Number (MPN) Method. Ten grams (g) of soil or ten ml of an aqueous sample was diluted with 90 ml of buffered saline. Four serial dilutions were prepared from the initial dilution and 5 ml of each serial dilution were placed into a row of test tubes (5 test tubes per dilution; one ml per tube) containing a nutrient solution plus methylene chloride as the primary source of carbon. The test tubes were incubated at 30°C for two weeks and then examined for presence or absence of growth. The number of positive tubes was compared to an MPN reference chart to estimate the magnitude of the microbial population in the original sample.

The results indicate that the existing microbial population in soil and groundwater includes a subpopulation of microorganisms capable of degrading methylene chloride. Stimulation of the methylene chloride-utilizing microorganisms with the proper nutrients as discussed in the following section, and oxygen should increase their percentage of the total microbial population and result in a significant decrease in the concentration of methylene chloride in the soil and groundwater.

1.3 Inorganic Nutrient Profile

A soil chemistry and groundwater chemistry profile was developed for the site. The soil sample used for the profile was a composite sample from boring C-SB-1 and the groundwater sample was from Monitoring Well C-MW11. The results of the soil and groundwater analyses are summarized in Table 2.

For the soil sample, the results indicate a heavy loamy soil with a high degree of cation exchange capacity. Although the salinity of the soil is normal, sodium is much higher than the other major cations. The existing concentration of the nutrient nitrogen as nitrate and ammonia could limit the potential for enhanced aerobic microbial degradation of methylene chloride.

The nutrient stock was added to the groundwater at a concentration of 10 ml of stock solution per liter of groundwater to provide a sufficient level of nutrients to facilitate biological growth.

To each high test aerobic microcosm (amber glass; 120 ml capacity; teflon faced silicon septa; aluminum crimp seals), 11.25 g of soil and 52.75 ml of amended groundwater was added in a controlled fashion to minimize volatilization of VOCs. To each diluted test aerobic microcosm (amber glass; 120 ml capacity; teflon faced silicon septa; aluminum crimp seals), 11.25 g of soil, 26.5 ml of amended groundwater and 26.5 ml of distilled water was added in a controlled fashion to minimize volatilization of VOCs. To each high test anaerobic microcosm (amber glass; 120 ml capacity; teflon faced silicon septa; aluminum crimp seals), 11.25 g of soil and 110 ml of amended groundwater (which was purged under nitrogen) was added to eliminate headspace (oxygen) and minimize volatilization of VOCs during the test period. Control microcosms were prepared by the addition of 11.25 g of soil, 6 ml of mercuric chloride ($HgCl_2$) stock solution (20 g Hg Cl_2 per liter of DI water) as a biocide, and 52.75 ml of amended groundwater in a controlled fashion. A total of 16 test microcosms and 6 control microcosms were prepared.

An aerobic environment was maintained in each aerobic test microcosm by replacing the headspace (approximately 60 ml) with oxygen on a biweekly basis. The headspace volume was extracted with a syringe advanced through the silicon septa. The syringe was refilled with oxygen and injected into the headspace of the microcosm. The silicon septum was sealed with a drop of wax following each injection. The killed control group was treated in the same fashion for replacing headspace as the aerobic test groups, thus any losses due to volatilization would be accounted for in the killed control. A redox indicator was added to the anaerobic microcosms to indicate that an anaerobic environment was present in the anaerobic test microcosm during the test period.

Although the primary chemical of concern at the site is methylene chloride, HLA performed a screening evaluation to determine the fate of other VOCs (PCE and TCE) present in the groundwater. Table 4 presents a analytical summary of other VOCs in the groundwater during the test period. The data represent estimated values for the PCE and TCE prior to dilution to quantify the methylene chloride concentration. The results indicate that a significant reduction was seen in all test groups as well as the killed control group. When the data are normalized to include losses observed in the control group, the data suggest that the majority of the removal of PCE and TCE during the test period was due to non-biological mechanisms.

TABLES

Table 1: Enumeration of Total and Methylene Chloride Utilizing Microorganisms in Soil and Groundwater
Region 6 Headquarters Site
Denver, Colorado

Sample Designation	Sample Type	Total Microorganisms	Methylene Chloride-Utilizing Microorganisms (percent of total)
C-SB-1	Soil	7.5×10^{3} *	3.9×10^{1} * (0.5)
C-MW20	Soil	9.9×10^{4} *	7.9×10^{2} * (0.8)
C-MW11	Water	$1.2 \times 10^{4\#}$	$1.3 \times 10^{3\#}$ (10.8)
C-MW16	Water	$2.7 \times 10^{4\#}$	$2.8 \times 10^{1\#}$ (0.1)

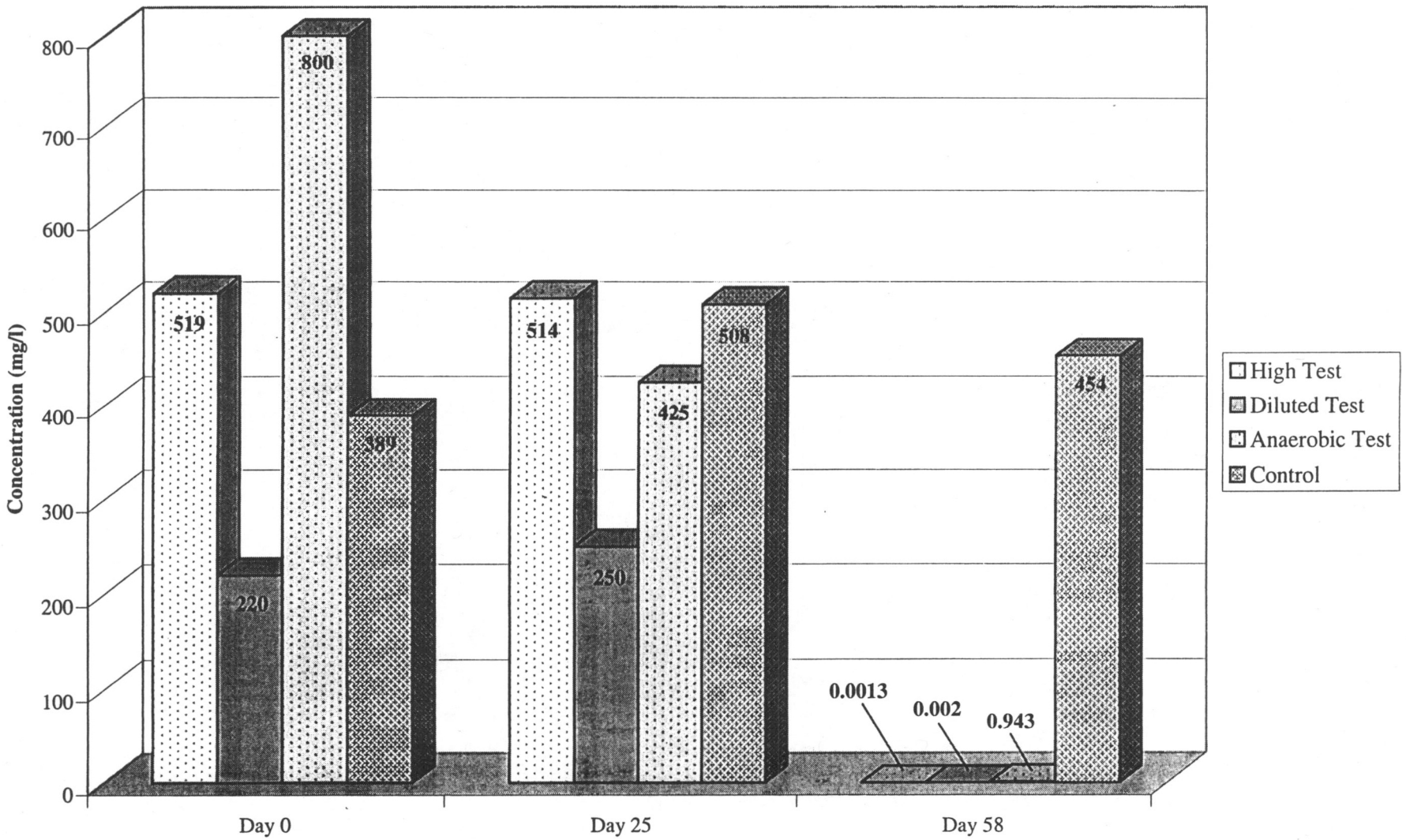
* Colony forming units per gram.
\# Colony forming units per milliliter.

Table 3: Degradation Rate Constant and Half-Life
Region 6 Headquarter Site
Denver, Colorado

Test Group	Degradation Constant (day^{-1})	Half-life (days)
Aerobic High	0.223	3.1
Aerobic Dilute	0.200	3.5
Anaerobic High	0.116	6.0

FIGURE

Figure E1: Methylene Chloride Concentration Versus Time



GROUNDWATER CORRECTIVE MEASURES PLAN
CDOT HEADQUARTERS FACILITY
MATERIALS TESTING LABORATORY
4340 EAST LOUISIANA AVENUE
DENVER, COLORADO

VOLUME II

Prepared for:
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SECOR Project No. B0187-001-04

December 17, 1998

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GROUNDWATER CORRECTIVE MEASURES PLAN
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MATERIALS TESTING LABORATORY
4340 EAST LOUISIANA AVENUE
DENVER, COLORADO

VOLUME II

Appendix A	Bench-scale Technology Feasibility Study - Microcosm Testing Final Report: Part A: Aerobic Biodegradation of Chlorinated Solvents
Appendix B	Bench-scale Technology Feasibility Study - Microcosm Testing Final Report: Part B: Anaerobic Biodegradation of Chlorinated Solvents
Appendix C	Bench Scale Chemical Oxidation Treatability Study (ISOTEC)
Appendix D	Bench-scale Technology Feasibility Study - Chemical Oxidation of Chlorinated Solvents: Final Report (Pelorus)

APPENDIX A

BENCH-SCALE TECHNOLOGY FEASIBILITY STUDY - MICROCOSM TESTING FINAL REPORT: PART A: AEROBIC BIODEGRADATION OF CHLORINATED SOLVENTS

BENCH-SCALE TECHNOLOGY FEASIBILITY STUDY CDOT HEADQUARTER FACILITY MATERIALS TESTING LABORATORY MICROCOSM TESTING FINAL REPORT: PART A: AEROBIC BIODEGRADATION OF CHLORINATED SOLVENTS

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December 1, 1998

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1.0 INTRODUCTION

This report presents the procedures and results of the aerobic biological bench-scale tests for the Colorado Department of Transportation (CDOT) - Materials Testing Laboratory (MTL) in Denver, Colorado (Site). The bench-scale feasibility study was used to evaluate the applicability of the aerobic biodegradation technologies on samples representative of impacted areas, downgradient to the MTL (Distal-Plume and Paleo-Channel Plume Areas). Impacts encountered in these areas are dissolved volatile organic compounds (VOCs) in groundwater including; 1,1,1 trichloroethane (1,1,1-TCA), trichloroethene (TCE) and 1,1-dichloroethene (1,1-DCE). Several mechanisms exist by which chlorinated solvents can be oxidized via co-oxidation or reduced, specifically through co-metabolism.

In groundwater, reductive transformations of chlorinated solvents are most often observed as a function of the incomplete transformation to chlorinated daughter products. One of the requirements for reductive dechlorination of chlorinated solvents is the presence of sufficient quantities of organic matter that can serve as electron donors for the process. Co-oxidative metabolism of chlorinated ethenes such as TCE are also possible in groundwater systems, although the intermediate products formed are very unstable and difficult to measure analytically. The oxidative degradation of chlorinated solvents such as TCE, DCE, vinyl chloride and TCA has been shown to be mediated by methane, ammonia, phenol and toluene oxidizing microorganisms.

Current scientific literature and investigations performed at a number of sites in the United States indicates that biodegradation of the target compounds found in the Distal- and Paleo-Channel Plume Areas is documented to occur. Based on previous investigations and analysis of groundwater monitoring data, it is apparent that significant *in situ* natural attenuation of released compounds occurs in the impacted groundwater at the Site. The presence of chlorinated solvent daughter products, formed from the primary released compounds, suggests that abiotic and biotic processes are occurring. This laboratory feasibility study was used to evaluate those naturally occurring processes and the enhancement of their performance to determine the biological mechanisms that exist and quantify the extent to which these processes affect the fate of the target compounds.

In situ aerobic biodegradation may be applicable for treating impacts downgradient to the MTL. Under aerobic conditions, chlorinated ethenes and 1,1,1-TCA have been shown to be biotransformed and biodegraded by microorganisms to innocuous by-products [i.e., carbon dioxide (CO_2), chloride ion (Cl^-), and biomass]. This process occurs with certain aerobic bacteria that use primary substrates such as phenol, toluene, cresol, methane, and propane for growth while degrading the chlorinated compounds by a process of co-oxidation. If the appropriate microorganisms are present, then by supplementing the system with the limiting inorganic nutrients or primary substrate(s), there is a reasonable opportunity to initiate *in situ* destruction of the chloroethenes. A detailed description of the aerobic biodegradation process for chlorinated solvents is presented in the Intrinsic Bio-Sampling Summary Report (Appendix F of the Groundwater Corrective Measures Plan).

The bench-scale testing described in this report was performed to evaluate the applicability of aerobic biodegradation processes for treating impacted soil and groundwater at the Site. The results show aerobic biodegradation processes are currently occurring at the Site and may be enhanced with the addition of organic and inorganic nutrients. The results also indicate 1,1,1-TCA, 1,1-DCE, DCM and TCE can be biologically degraded aerobically with various nutrient additions.

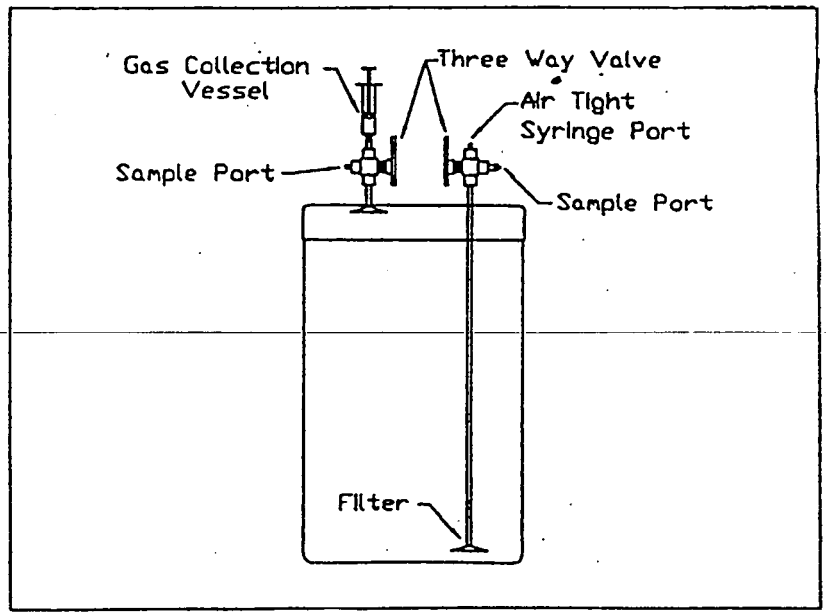
3.0 METHODOLOGY

This section presents the aerobic microcosm testing methodology, including soil and groundwater preparation, monitoring and analytical testing. Aerobic microcosm protocols are an adaptation of the methodologies developed by the US Environmental Protection Agency and presented in the "Technical Protocol For Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater" (AFCEE, 1996).

3.1 MATERIAL PREPARATION

Microcosm studies were conducted in modified 4.0 liter glass bottles as illustrated below. The modified bottles were equipped with three-way sample valves that allow for removal of liquid and/or headspace samples with minimal potential for loss of volatile constituents during testing. Each microcosm contained 1600 grams of soil (MW-96) and 2.0 liters of groundwater (MW-59) spiked with target constituents. A total of 16 microcosms were prepared for these tests (15 test conditions and one control). The methods for preparing the microcosms are summarized below.

Schematic of Test Apparatus for Aerobic Microcosm Testing



The soil sample was thoroughly mixed immediately prior to weighing out 1600-gram lots for each of the fifteen microcosm jars. The 1600-gram lots were then placed in the microcosm jars and sealed with Teflon lined lids. The screw threads around the jar neck for the lid were wrapped with Teflon tape to ensure a tight seal. This was demonstrated by pressurizing the jars to 5 pounds per square inch (psi) with nitrogen and checking for pressure loss (i.e., leaks) over a 24 hour time period. Random microcosms (5 in total) were then pressurized to 10 psi with air and the pressure loss monitored for 7 days. A maximum pressure loss of 2 psi was observed over 48 to 72 hours after which no further pressure drop was observed.

The groundwater sample was combined into a 5-liter container and sparged with nitrogen for 45 minutes to remove VOC's from the water. The pH and dissolved oxygen was then compared to the values obtained in the field and adjusted when necessary. The water was then dispensed into 10-liter Tedlar bags using a peristaltic pump and spiked with 1,1-DCE, 1,1,1-TCA, and TCE to bring the concentration of each compound to a target concentration of 100 ug/L. The spiked groundwater was then added to each microcosm in 2.0-liter aliquots. The microcosms were then wrapped in aluminum foil to prevent access

Monitoring of the primary substrates, propane and methane, was accomplished by collecting a 1.0 ml sample and placing it in a 2.0 ml crimp seal GC vial. The vial was equilibrated and the headspace monitored by GC/FID. The phenol series was monitored for phenol concentrations by collecting 5.0 ml samples that were analyzed using a colorimetric procedure. Dissolved oxygen was checked qualitatively against a Resazurin Dye indicator. Sampling of the microcosms for VOC's occurred at weeks 0, 1, 2, 4, and 8. Samples were collected by connecting an airtight syringe with a luer lock fitting to the 3-way luer lock valve, then transferring the sample to a VOA vial that was submitted for analysis. The volume removed for analysis was replaced simultaneously with prepared groundwater from the 10-liter Tedlar bag stock solutions which had been stored at 4 degrees C.

3.3 ESTIMATING BIODEGRADATION RATES

Data plots and transformations were performed in an MS Excel 7.0 environment using methods similar to those that have been recently described as the Buschek Method (Buschek et al., 1997). After plotting microcosm concentration data versus time, a "Trendline" is inserted for each constituent. An "Exponential" function is applied to the trendline and the equation for the trendline is displayed. The exponential equation is a first order function in the form of Equation 1.

$$y = C_0 e^{-kt} \qquad \textit{Equation 1}$$

A further description of this process as related specifically to these aerobic microcosm studies is presented in Section 4.3, Estimations of Rate Constants. To obtain half-life estimates from the degradation rate constant data the following transformation can be applied:

$$T_{1/2} = -0.693/k \qquad \textit{Equation 2}$$

Due to the observed losses in the sterile controls, the unamended series was used to establish a "pseudo" baseline of subsurface processes. The term "pseudo" is used because the unamended microcosm series is not a true representation of subsurface conditions, in that variables such as; temperature, soil surface area to water ratio, and groundwater movement through the soil are not representative. In addition, the unamended microcosms were supplemented with aerated groundwater containing 5.0-6.5 mg/L of dissolved oxygen. Because the subsurface environment at this Site is a fractured sandstone, siltstone, claystone bedrock, the actual soil surface area in contact with flowing groundwater is relatively low as compared to an unconsolidated system, as simulated in the microcosms. During the first two weeks of microcosm testing, the soil in the microcosms became less consolidated resulting in a higher soil surface area to water ratio. This higher surface area will result in significantly higher sorption/desorption rates in the microcosms as compared to the *in situ* process. Consequently, there is also greater surface area for microbial attachment and growth resulting in potentially higher population densities and degradative activity.

Considering the aforementioned factors, it is apparent that microcosms acclimated to methane as a primary carbon source, proliferated more quickly as compared to the microcosms amended with propane or phenol. At the eighth week however, the overall reduction of individual target constituent levels in these three microcosm series were comparable as presented in Table 3. The exception was DCM. Only the methane series showed discernable differences in the rate and extent of DCM degradation as compared to the unamended series. DCM is one of the few chlorinated solvents that can be used as a growth substrate by a wide range of aerobic and anaerobic microorganisms that metabolize one carbon compounds (i.e., C-1) for their existence. The higher efficiencies of DCM degradation in the methane-supplemented microcosms may be due to this remote similarity of the molecular structure of DCM and methane (i.e., C-1 carbon sources). These results suggest that the indigenous phenol, methane and propane utilizing microbial populations could be stimulated to co-oxidatively degrade the target constituents.

The enhanced chlorinated solvent reduction rates in the microcosms that were amended with inorganic nutrients and/or a primary carbon source is not surprising in view of the low concentrations of target constituents observed in the native soil and groundwater during the initial material characterization. Reduction of target compounds in microcosms receiving nutrients alone suggests that there may be a reservoir of organic matter in the soil and groundwater within the Distal-Plume Area which provides primary growth substrates for the indigenous microbial populations. For example, it is well known that Methanotrophs and other C-1 utilizing microbes can co-oxidize chlorinated solvents. In addition, microorganisms that degrade aromatic compounds (e.g., BTEX, phenols) are also known to possess the capability of co-oxidizing chlorinated solvents. Microbial production of phenols (e.g., phenol, cresols) from BTEX constituents is a well-documented aspect of microbial metabolism as is the production of methane from the fermentation of certain BTEX constituents. The presence of aromatic hydrocarbons in the Source Area at the MTL is well documented and, therefore, the groundwater flowing from the Source Area may contain phenolic metabolite compounds or methane, which can support the observed activity in inorganic-nutrient supplemented microcosms. Results obtained in these microcosm tests are consistent with the hypothesis that, uncharacterized carbon sources may be flowing into the Distal-Plume Area from upgradient sources thereby providing co-substrates for the microbial degradation of the target constituents.

Although it is a known release compound, microcosms were not initially spiked with methylene chloride (i.e., DCM or dichloromethane) since this constituent does not appear to be above action levels outside the Source Area of the plume. However, it has been included in the observations due to its appearance in the microcosms from the initial time point. The source of the methylene chloride in the groundwater may be a result of its desorption from the aquifer sediments. As observed in these studies there appears to be a potential reservoir of DCM in the soils used for these tests. Microbial populations capable of growing on DCM as a sole food source are well documented in the bioremediation literature. As such, these populations may be significant contributors to the observed biodegradation of the target constituents.

4.3 ESTIMATIONS OF RATE CONSTANTS

Microcosm degradation curves (Figures 2 through 5) were constructed using the mean value of three replicate samples for each time point. Because of the observed potential for sorptive or other abiotic losses, a trend line or curve of best fit was generated for the data from week 1 through week 8. To obtain a 1st Order rate constant, an exponential curve fit was applied to the data and regression analysis used to define the fitness of the curve to the experimental data. In many instances, a 2nd or 3rd order polynomial function best described the experimental data indicating that the overall rate of degradation in the microcosms is complex and probably the sum of multiple processes (i.e., oxygen transfer, primary substrate, sorption/desorption) and not first order with respect to substrate concentration. However, microbial degradative processes are enzymatic and enzyme reactions are usually first-order with respect to substrate, therefore for modeling purposes, the first order reaction was defined according to the equation:

$$y = C_0 e^{-kt} \qquad \textit{Equation 3}$$

Where: C_0 is the initial substrate concentration, t is time and k is the 1st order rate constant.

The rate equations obtained for each of the target compounds in each test series, as listed Table 3, are in the form of Equation 3. The rates obtained from these equations for each constituent and condition have been converted to an annual rate basis and summarized in Table 4.

5.0 CONCLUSIONS

The results obtained from these microcosm tests suggest that the enhancement of the indigenous aerobic biodegradation activity may be achieved through the amendment of ground water with a supply of inorganic nutrients and a supplemental carbon source such as methane. As such, aerobic co-oxidation of target constituents is a fate mechanism that is active in the soil and groundwater in this area of the plume. Methanotrophic microorganisms are widely distributed in the environment. In the Denver area there is a significant opportunity for methane, as well as hydrogen and other light hydrocarbon gases, to seep from subsurface coal beds and migrate towards the surface. Such natural supplies may be responsible for the observed methanotrophic response in these tests. The methanotrophic populations within the impacted soil and groundwater in the Paleo-Channel Plume Area appears to be adapted to provide biodegradation of the target constituents as noted by the lack of an acclimation period in the microcosm tests. An implication of this finding is that when implementing the process in a field setting there should be a similar immediate response once adequate mixing and distribution of the nutrients, oxygen and methane occurs *in situ*.

The observed response with a simple nutrient addition suggests that there may be a sufficient, though not quantified, supply of organic matter that is supporting the co-oxidation of the target compounds. As mentioned previously; aromatic hydrocarbons, phenolic compounds as well as methylene chloride (DCM) are primary carbon sources that can be used by microorganisms to support *in situ* growth and co-oxidative activities. It appears that DCM is desorbing from the downgradient sediments used in these tests, based on the fact that DCM was not included as a constituent addition to the spike solution. The fact that groundwater monitoring data from the Site shows no detectable DCM in the Distal-Plume and Paleo-Channel Areas indicates that natural occurring *in situ* microbial activity is biologically degrading this compound to below detectable limits. Thus, the ability to enhance the natural microbial populations *in situ* could significantly improve groundwater quality in the Distal-Plume Area.

One of the concerns with laboratory microcosm testing data is the fact that it is very difficult to precisely simulate *in situ* conditions. Temperature has a major influence on biological reaction rates. To place a conservative boundary condition on the rates developed in these microcosm studies, a rate correction can be applied to the data using an Arrhennius correction factor based on constituent activation energies and the temperature differential. Equation 4 can be used to calculate rate constants at different temperatures assuming A and E_a are temperature dependent, which is a reasonable approximation for biologically catalyzed reactions.

$$k = A * e^{-Ea/RT} \qquad \textit{Equation 4}$$

Where; A is the frequency factor and E_a is the activation energy.

Depending on the magnitude of E_a, a 10 degrees C change in temperature can increase or decrease the reaction by a factor of 2 to 6. Assuming an average activation energy for the chlorinated constituents in this study a 10 degrees C increase in temperature can increase the rates by a factor of 4 (Schwarzenbach et al., 1993). Thus, for modeling purposes and analysis of *in situ* processes at the Site, the rates developed in these microcosm tests can be bounded at the lower end by assuming a 4-fold lower rate *in situ*. Since the aquifer material selected for microcosm testing was from the Paleo-Channel Area of the plume, it may be prudent to analyze other areas of the plume for the presence of similar microbial populations, specifically, phospholipid fatty acid (PLFA) can be performed to determine total viable population levels and the nutritional status and health of these populations. Furthermore, characterization of specific degradative enzymes as well as the corresponding genes necessary to target constituent degradation can be determined and compared with the microcosm materials. These types of analyses can

6.0 LITERATURE CITED

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Schwarzenbach, R.P., P.M. Gschwend and D.M. Imboden. *Environmental Organic Chemistry*, John Wiley & Sons, Inc., New York, N.Y., 1993, p348.

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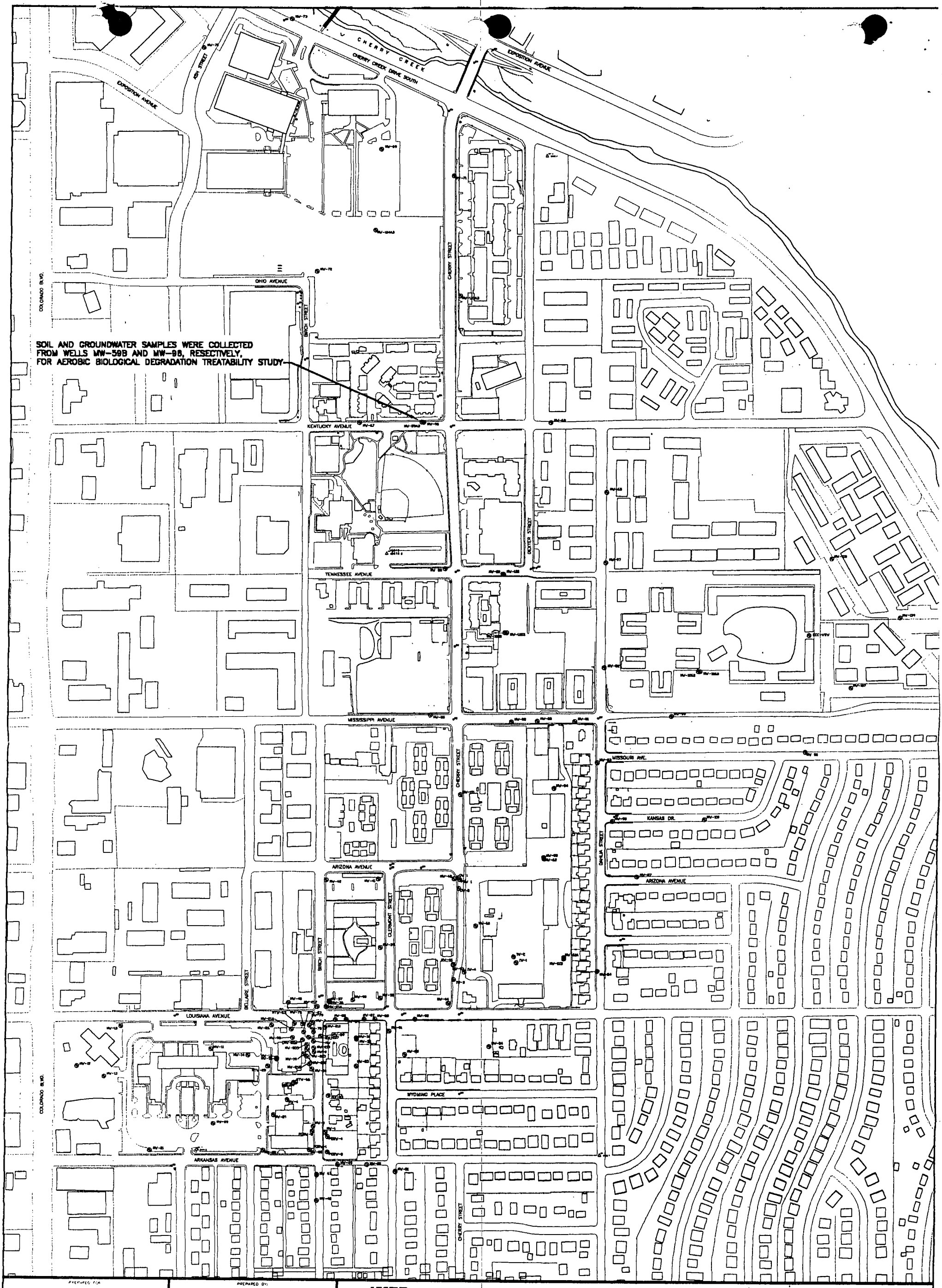
FIGURES



CDOT MATERIALS TESTING LABORATORY PROJECT

4340 EAST LOUISIANA AVENUE
DENVER, COLORADO

AEROBIC BIODEGRADATION BENCH-SCALE TESTING SAMPLE LOCATIONS

FIGURE 1

PREPARED BY:

SECOR INTERNATIONAL INCORPORATED

SECOR

355 UNION BOULEVARD
SUITE 200
LAKEWOOD, COLORADO 80228

DESIGNED BY:	DETAILED BY:	CHECKED BY:
	MTH	

DATE:	ACAD FILE:
12/15/98	SLM-0992

PROJECT NO.:	PLOT SCALE:
80187-001-04	1" = 200'

LEGEND

- MONITORING WELL LOCATION AND DESIGNATION
- RECOVERY WELL LOCATION AND DESIGNATION

NOTE:
1. NOT ALL WELLS IN THE VICINITY OF THE MTL ARE PRESENTED FOR CLARITY.

N

0 200 400
SCALE IN FEET

Figure 2. Aerobic Microcosm
Replicate Average Reduction of 1,1,1-Trichloroethane

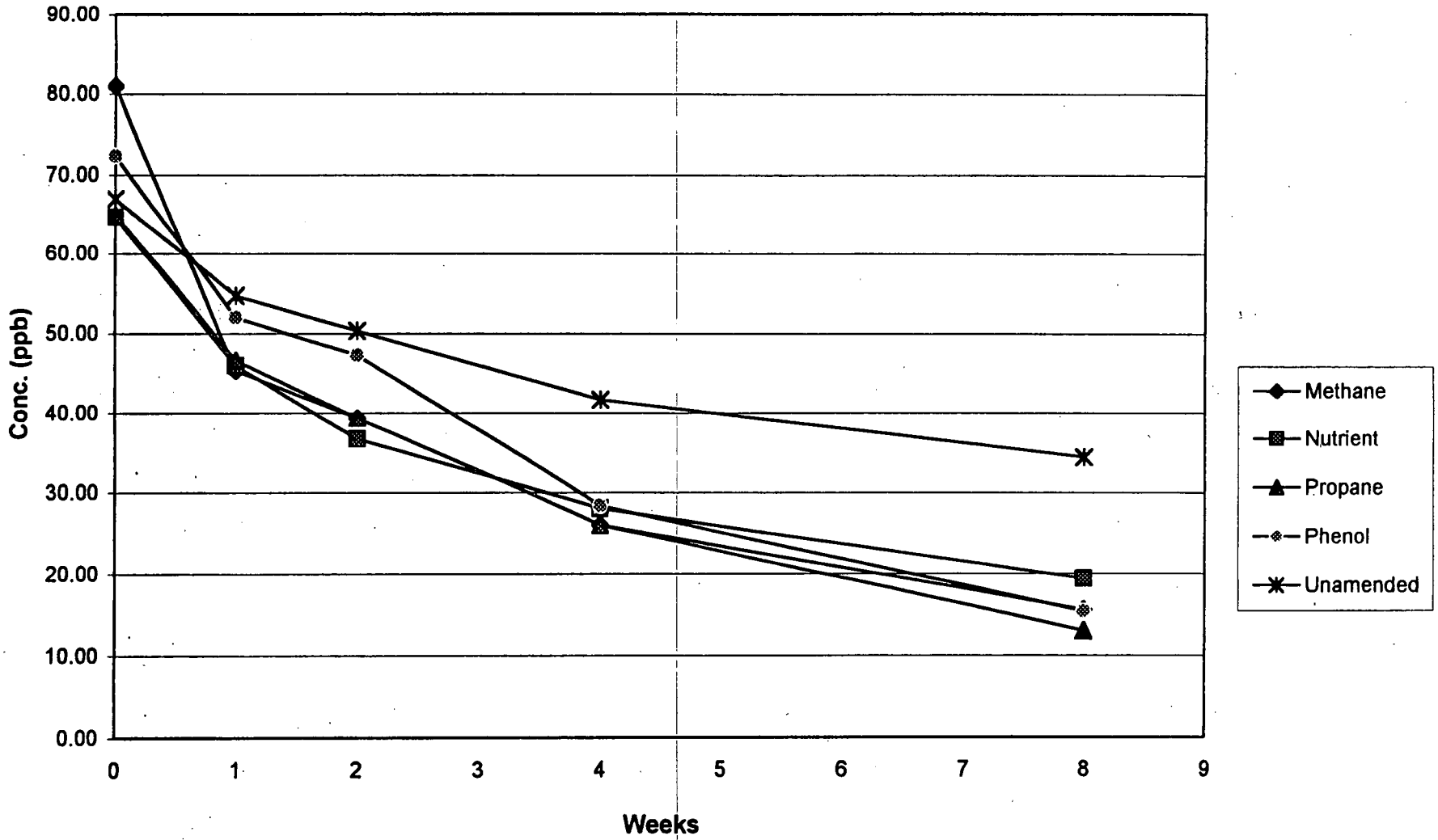


Figure 3. Aerobic Microcosm
Replicate Average Reduction of 1,1-Dichloroethylene

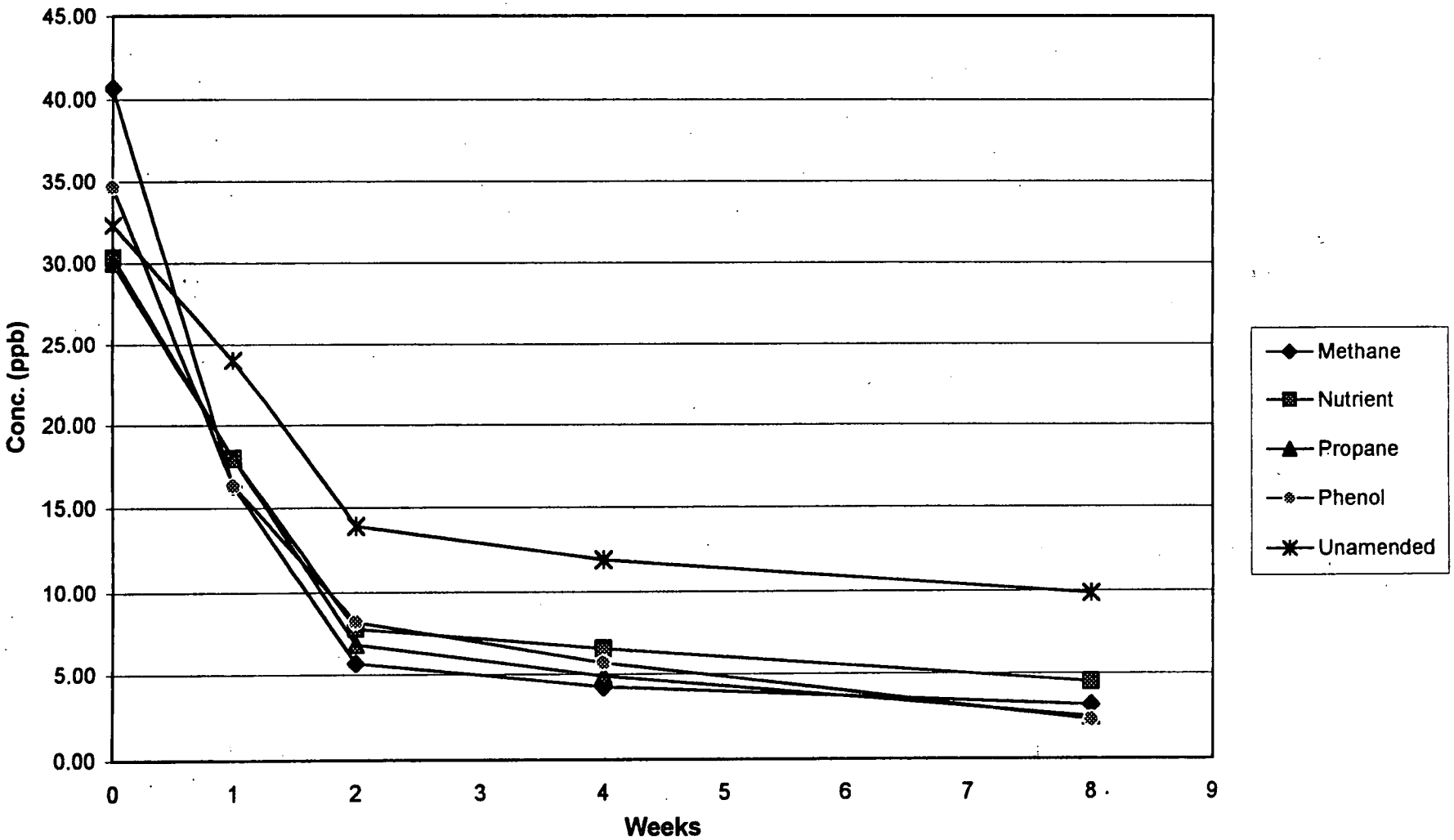


Figure 4. Aerobic Microcosm
Replicate Average Reduction of Methylene Chloride

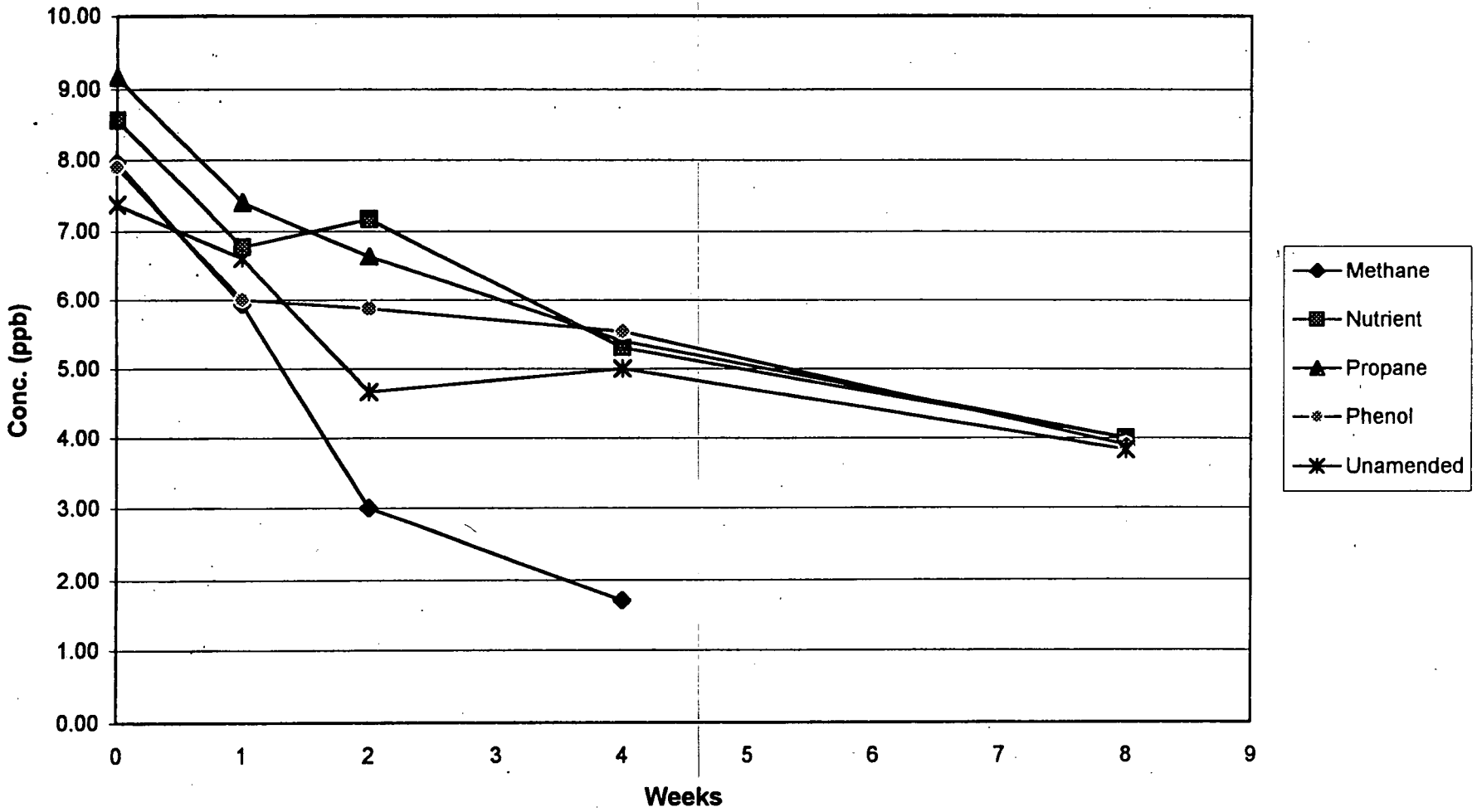


Figure 5. Aerobic Microcosm
Replicate Average Reduction of Trichloroethylene

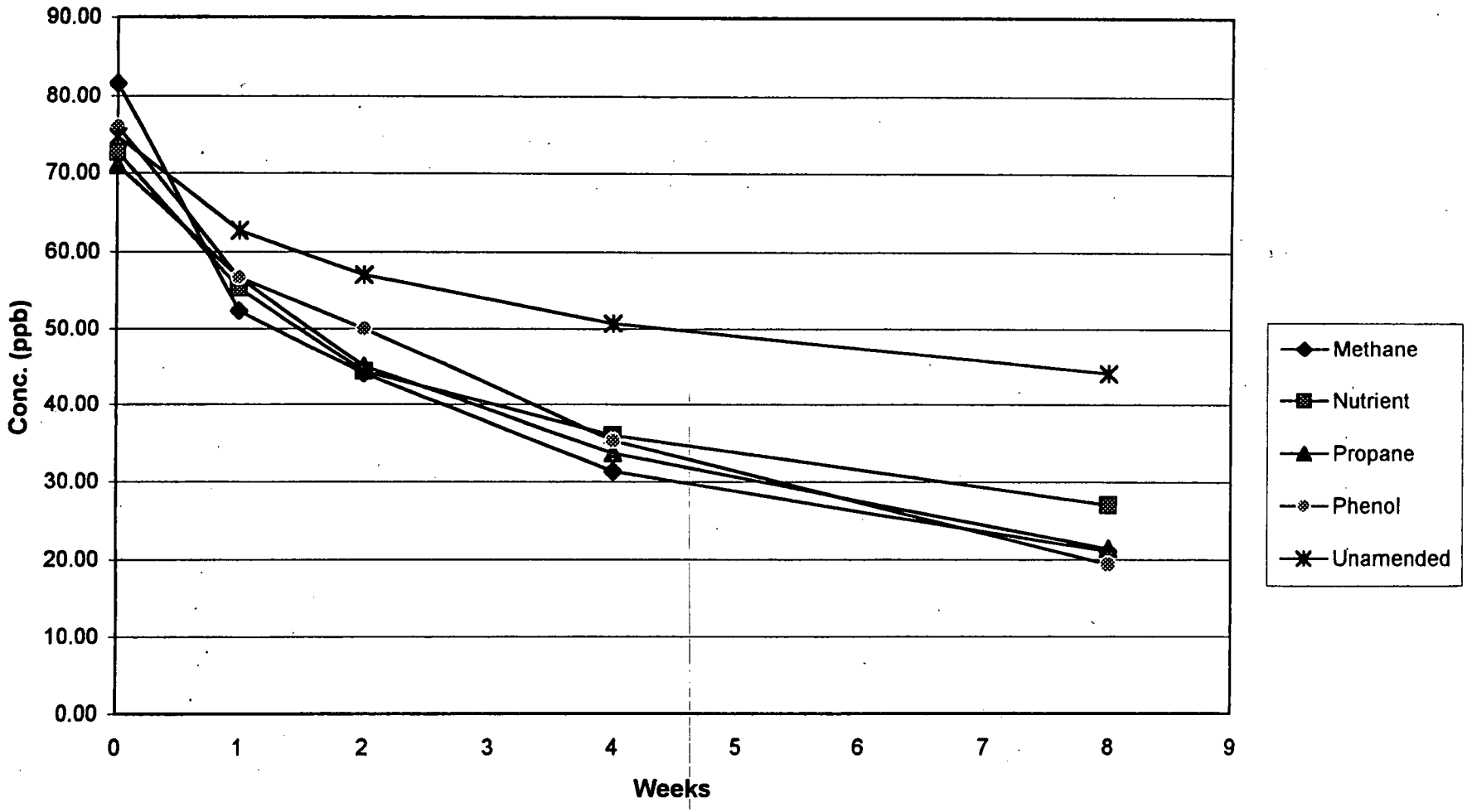


Figure 6. Aerobic Microcosm
Unamended Replicate Average vs. Sterile Control

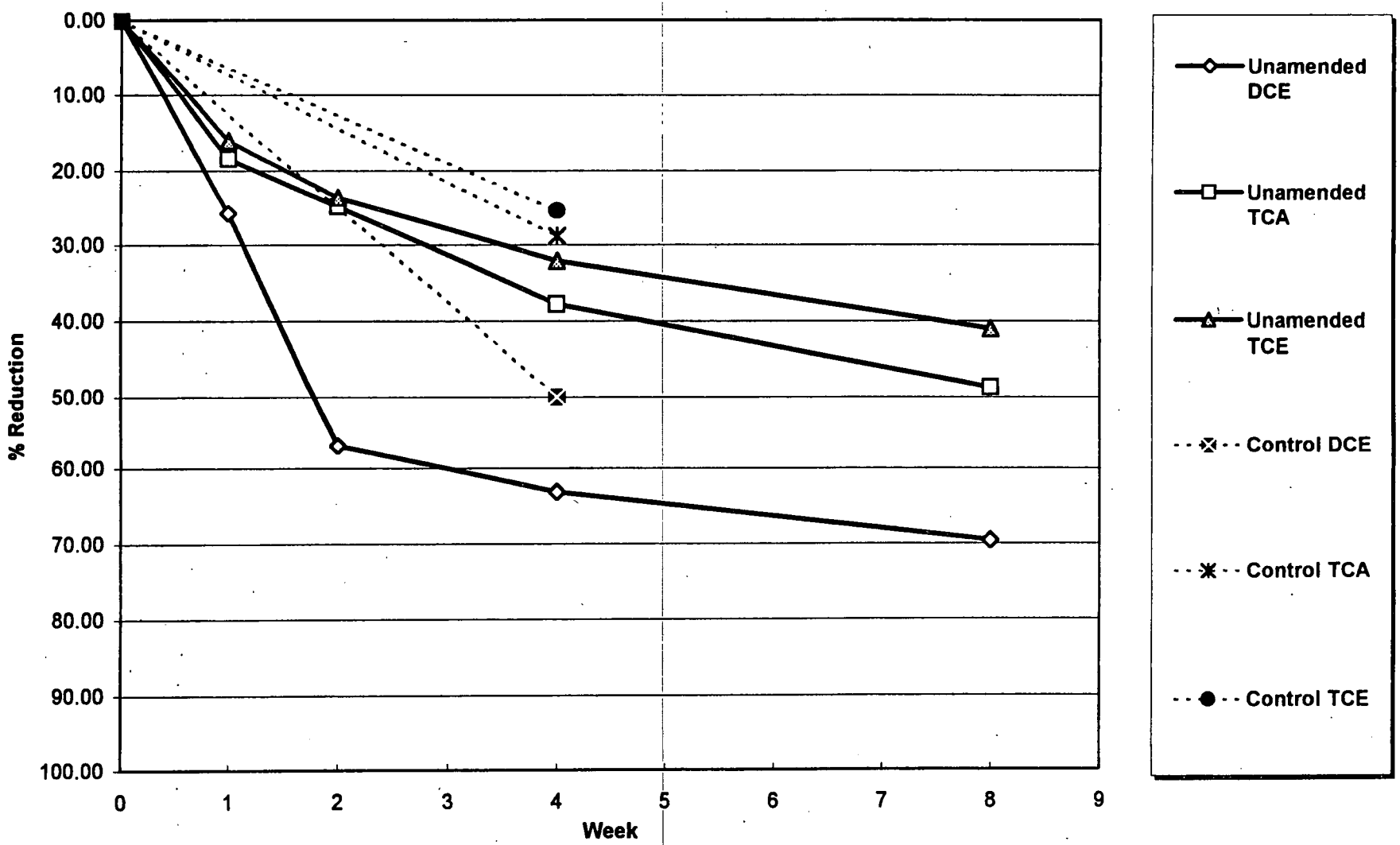
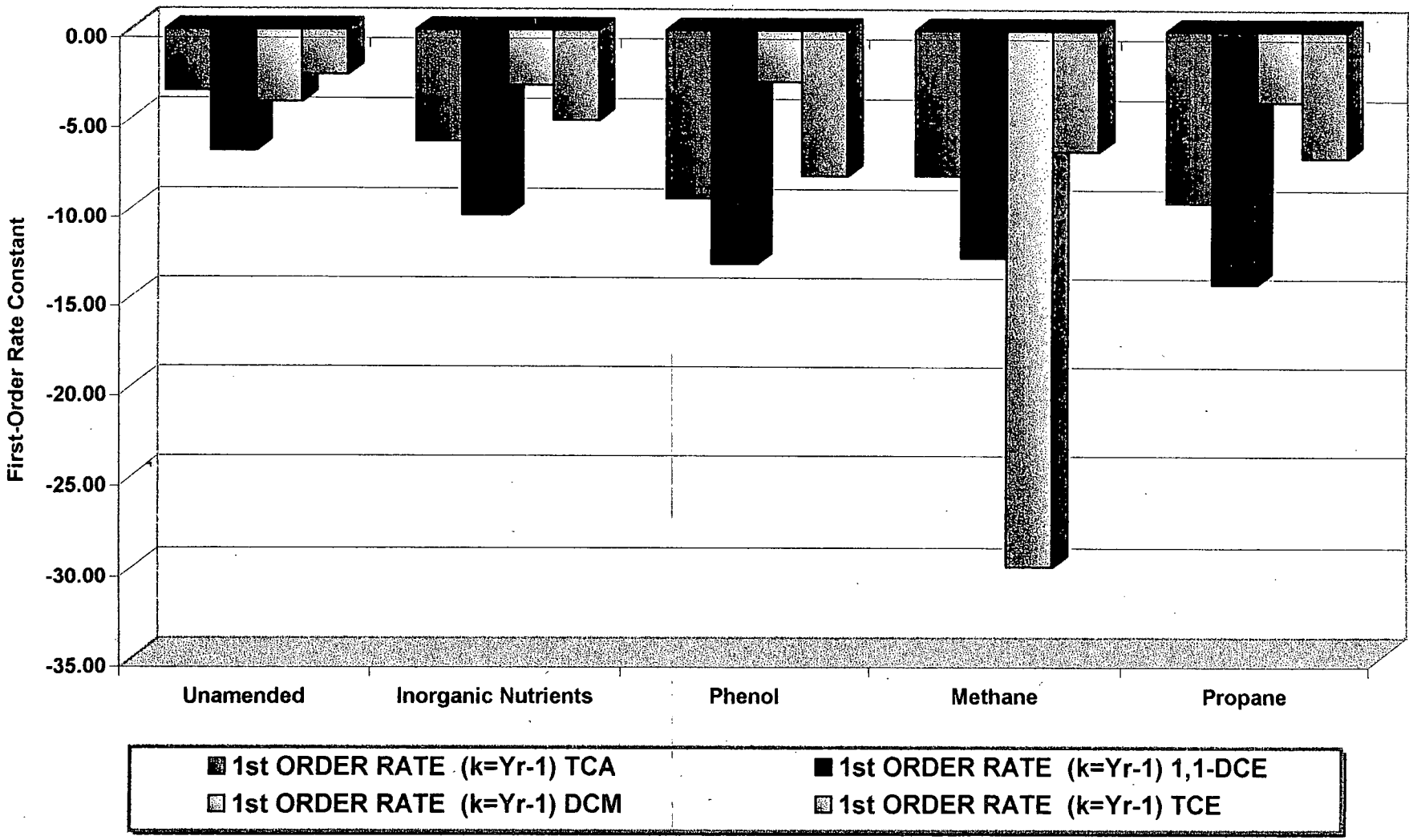


Figure 7. Aerobic Microcosm Rate Constants ($k=Yr^{-1}$)



ATTACHMENT B

ANALYTICAL DATA TABLES

Summary of Groundwater Analytical Results: wells near and upgradient of source area

	Background Wells			
Well ID	C-MW19D	C-MW19D	C-MW19S	C-MW19S
Sample Date	3/18/99	6/9/99	3/18/99	6/9/99
Well Depth	36.5'	36.5'	24.9'	24.9'
Compound (µg/l)				
Dichlorodifluoromethane	10 U	10 U	10 U	10 U
Chloromethane	10 U	10 U	10 U	10 U
Vinyl chloride	10 U	10 U	10 U	10 U
Bromomethane	10 U	10 U	10 U	10 U
Chloroethane	10 U	10 U	10 U	10 U
Trichlorofluoromethane	10 U	10 U	10 U	10 U
1,1-Dichloroethene	5 U	5 U	5 U	5 U
Acetone	100 U	10 U	100 U	10 U
Iodomethane	50 UJ	10 U	50 U	10 U
Carbon disulfide	5 U	5 U	5 U	5 U
Methylene chloride	5 U	5 U	5 U	5 U
trans-1,2-Dichloroethene	5 U	5 U	5 U	5 U
2-Methoxy-2-methylpropane	5 U	5 U	5 U	5 U
1,1-Dichloroethane	5 U	5 U	5 U	5 U
Vinyl acetate	50 U	10 U	50 U	10 U
2,2-Dichloropropane	5 U	5 U	5 U	5 U
cis-1,2-Dichloroethene	5 U	5 U	5 U	5 U
2-Butanone	50 U	10 U	50 U	10 U
Bromochloromethane	5 U	5 U	5 U	5 U
Chloroform	5 U	5 U	5 U	5 U
1,1,1-Trichloroethane	5 U	5 U	5 U	5 U
1,1-Dichloropropene	5 U	5 U	5 U	5 U
Carbon tetrachloride	5 U	5 U	5 U	5 U
Benzene	5 U	5 U	5 U	5 U
1,2-Dichloroethane	5 U	5 U	5 U	5 U
Trichloroethene	5 U	5 U	5 U	5 U
1,2-Dichloropropane	5 U	5 U	5 U	5 U
Dibromomethane	5 U	5 U	5 U	5 U
Bromodichloromethane	5 U	5 U	5 U	5 U
2-Chloroethyl vinyl ether	5 U	10 U	5 U	10 U
cis-1,3-Dichloropropene	5 U	5 U	5 U	5 U
4-Methyl-2-pentanone	50 U	10 U	50 U	10 U
Toluene	5 U	5 U	5 U	5 U
trans-1,3-Dichloropropene	5 U	5 U	5 U	5 U
1,1,2-Trichloroethane	5 U	5 U	5 U	5 U
1,2-Dibromoethane	5 U	5 U	5 U	5 U
Tetrachloroethene	5 U	5 U	5 U	5 U
1,3-Dichloropropane	5 U	5 U	5 U	5 U
2-Hexanone	50 U	10 U	50 U	10 U
Dibromochloromethane	5 U	5 U	5 U	5 U
Chlorobenzene	5 U	5 U	5 U	5 U
1,1,1,2-Tetrachloroethane	5 U	5 U	5 U	5 U
Ethylbenzene	5 U	5 U	5 U	5 U
m,p-Xylenes	5 U	5 U	5 U	5 U

Summary of Groundwater Analytical Results: wells near and upgradient of source area

	Background Wells			
Well ID	C-MW19D	C-MW19D	C-MW19S	C-MW19S
Sample Date	3/18/99	6/9/99	3/18/99	6/9/99
Well Depth	36.5'	36.5'	24.9'	24.9'
Compound (µg/l)				
o-Xylene	5 U	5 U	5 U	5 U
Styrene	5 U	5 U	5 U	5 U
Bromoform	5 U	5 U	5 U	5 U
Isopropylbenzene	5 U	5 U	5 U	5 U
Bromobenzene	5 U	5 U	5 U	5 U
1,1,2,2-Tetrachloroethane	5 U	5 U	5 U	5 U
1,2,3-Trichloropropane	5 U	5 U	5 U	5 U
Propylbenzene	5 U	5 U	5 U	5 U
2-Chlorotoluene	5 U	5 U	5 U	5 U
4-Chlorotoluene	5 U	5 U	5 U	5 U
1,3,5-Trimethylbenzene	5 U	5 U	5 U	5 U
tert-Butylbenzene	5 U	5 U	5 U	5 U
1,2,4-Trimethylbenzene	5 U	5 U	5 U	5 U
sec-Butylbenzene	5 U	5 U	5 U	5 U
1,3-Dichlorobenzene	5 U	5 U	5 U	5 U
4-Isopropyltoluene	5 U	5 U	5 U	5 U
1,4-Dichlorobenzene	5 U	5 U	5 U	5 U
1,2-Dichlorobenzene	5 U	5 U	5 U	5 U
Butylbenzene	5 U	5 U	5 U	5 U
1,2-Dibromo-3-chloropropane	5 U	5 U	5 U	5 U
1,2,4-Trichlorobenzene	5 U	5 U	5 U	5 U
Hexachlorobutadiene	5 U	5 U	5 U	5 U
Naphthalene	5 U	5 U	5 U	5 U
1,2,3-Trichlorobenzene	5 U	5 U	5 U	5 U

Appendix B

GROUNDWATER MONITORING PLAN

CONTENTS

B.1 INTRODUCTION

This groundwater monitoring plan presents the target analytes/parameters, sampling frequency, and sampling locations for the groundwater monitoring activities associated with monitoring the active biodegradation pilot-scale testing. The specific objectives of the groundwater monitoring program are as follows:

- Collect data to assess the effectiveness and area of influence of injection
- Collect data to facilitate system optimization and develop a design basis for full scale design and implementation

The groundwater monitoring program will also support the following overall objectives of the pilot test:

- Assess whether the conditions within the groundwater flow system beneath the Site are conducive to stimulating the methylene chloride-utilizing microbial population
- Evaluate impacts to the groundwater gradient and rate of the treatment front breakthrough in the formation at a nearby downgradient monitoring point
- Evaluate whether co-metabolic degradation of more highly chlorinated compounds (e.g., 1,1-DCE, TCE, and PCE) is occurring.

The remainder of this appendix is divided into the following sections:

- Water-level Monitoring
- Field Parameter Monitoring
- Baseline Groundwater Sampling
- Operational Groundwater Sampling
- Sampling, Analytical, and Quality Assurance Procedures
- Data Management

B.2 WATER-LEVEL MONITORING

Water-level monitoring will initially be performed to establish a baseline prior to startup, on a weekly basis during startup, followed by semi-monthly during operations. Table B.1 presents the frequency of water-level measurements for the wells included in the sampling network. Additional wells included in the water-level monitoring network are presented below. The water-levels in the injection wells may not be measured if the wellbore is under pressure and cannot be accessed.

Well Number	Well Number
Upper Zone	**Lower Zone**
C-IW1A	C-IW2B
C-MW20S	C-MW30B
C-MW29A	C-MW20D
C-MW23	C-OBS1B 70 ft downgrad
C-OBS2A	C-MW16S 80ft downgrad · 16.1 mg/L nitrate as N
C-OBS1A	C-OBS2B
R-MW7	C-MW21D
C-MW15S	R-MW37B
C-MW21S	C-MW15D
C-MW22	C-MW18D
R-MW37	C-MW17S
C-MW18S	C-MW17D 15.7 mg/L nitrate as N
C-MW9	
C-MW10	

100' downgrad 9-18ft/yr

B.3 FIELD PARAMETER MONITORING

Field parameter monitoring will initially be performed to establish baseline conditions prior to system startup. Subsequent to system startup, field parameter monitoring will be performed on a weekly basis during startup followed by semi-monthly during operations. Table B.1 presents the frequency of water-level measurements for the wells included in the sampling network. The field kit or meter used for each of the field parameters is presented below. Field parameters in the injection wells may not be measured if the wellbore is under pressure and cannot be accessed.

Analysis	Method
Phosphate (nutrient)	Hach Field Kit
Carbon Dioxide (indicator)	Hach Field Kit
pH	Orion 250A
Conductivity	YSI Model 30
Oxidation/Reduction Potential	Orion 250A
Dissolved Oxygen	YSI Model 55
Temperature	Orion 250A

B.4 BASELINE GROUNDWATER MONITORING

To establish the in-situ background conditions in the zones of interest a baseline groundwater sampling event will be performed. Each well will be purged using a stainless steel bailer until three saturated casing volumes have been removed from each well. Groundwater samples to be analyzed for VOCs and methane will then be collected using a low flow-regulator attached to the stainless steel bailer. Should a well de-water while purging, the well will be allowed to recover until sufficient volume is available to allow the collection of the sample suite. The bailer will be decontaminated after use in each well. Purge water and decontamination water will be containerized in a truck-mounted tank and transferred to a larger storage tank at the IDW staging area on the Site.

As part of the initial baseline groundwater sampling event, HLA will sample four wells including:

- One new upper zone well C-MW29A
- Existing upper zone well C-MW20S
- One new lower zone well C-MW30B
- Existing lower zone well C-MW20D.

The samples collected during baseline monitoring will be analyzed for the same constituents to be monitored during the operation of the pilot-scale test. The evaluation of whether the pilot-scale test is having the desired impact involves the tracking of the injected nutrient parameters and the characterization of parameters directly and indirectly related to biological activity. These parameters provide data on treatment front propagation, microbial activity, concentrations of dissolved contaminants, concentrations of potential electron acceptors (dissolved oxygen), concentrations of biodegradation byproducts (carbon dioxide), and general geochemical conditions (chemical oxygen demand [COD], pH, alkalinity, and oxidation-reduction potential [ORP]). Thus, the parameters to be monitored in the baseline assessment are presented below:

Analysis	Method
VOCs	8260B
Methane	EPA 8000 Modified
Nitrate as Nitrogen	EPA 300.0
Ammonia	EPA 350.3
Sulfate	EPA 375.4
Chloride	EPA 325.2
Alkalinity to pH 8.3	EPA 310.1
Alkalinity to pH 4.5	EPA 310.1
Phosphate	Hach Field Kit
Carbon Dioxide	Hach Field Kit
pH	Field Measurement
Conductivity	Field Measurement
Oxidation/Reduction Potential	Field Measurement
Dissolved Oxygen	Field Measurement
Temperature	Field Measurement
Chemical Oxygen Demand	EPA 410.4
Total Organic Carbon	EPA 415.1
Dissolved Organic Carbon	EPA 415.1
Aerobic microbial count	Laboratory Methods

B.5 OPERATIONAL GROUNDWATER MONITORING

Operational groundwater monitoring will be performed under a separate task order. The operational groundwater monitoring will consist of purging each well using a stainless steel bailer until three saturated casing volumes have been removed from each well. Groundwater samples to be analyzed for VOCs and methane will then be collected using a low flow-regulator attached to the stainless steel bailer. Should a well de-water while purging, the well will be allowed to recover until sufficient volume is available to allow the collection of the sample suite. The bailer will be decontaminated after use in each well. Purge water and decontamination water will be containerized in a truck-mounted tank and transferred to a larger storage tank at the IDW staging area on the Site.

As part of the operational groundwater sampling events, HLA will sample four wells as presented in Table B.1 including the following:

- One new upper zone well C-MW29A ~12 ft downgradient
- Existing upper zone well C-MW20S 5-7 ft downgradient
- One new lower zone well C-MW30B 5 ft downgradient
- Existing lower zone well C-MW20D. 30 ft upgradient

3 months 9 ft/yr move 2.25 ft 18 ft/yr move 4.5 ft — 6 months 4.5 ft 9 ft

3 months 39 ft/yr 9.75 ft — 6 months 19.5 ft

The samples collected during operational monitoring will be analyzed for the constituents as during the baseline groundwater monitoring event. The evaluation of whether the pilot-scale test is having the desired impact involves the tracking of the injected nutrient parameters and the characterization of parameters directly and indirectly related to biological activity. These parameters provide data on treatment front propagation, microbial activity, concentrations of dissolved contaminants, concentrations of potential electron acceptors (dissolved oxygen), concentrations of biodegradation byproducts (carbon dioxide), and general geochemical conditions (chemical oxygen demand [COD], pH, alkalinity, and

oxidation-reduction potential [ORP]). Thus, the parameters to be monitored in the baseline assessment are presented below:

Analysis	Method
VOCs	8260B
Methane	EPA 8000 Modified
Nitrate as Nitrogen	EPA 300.0
Ammonia	EPA 350.3
Sulfate	EPA 375.4
Chloride	EPA 325.2
Alkalinity to pH 8.3	EPA 310.1
Alkalinity to pH 4.5	EPA 310.1
Phosphate	Hach Field Kit
Carbon Dioxide	Hach Field Kit
pH	Field Measurement
Conductivity	Field Measurement
Oxidation/Reduction Potential	Field Measurement
Dissolved Oxygen	Field Measurement
Temperature	Field Measurement
Chemical Oxygen Demand	EPA 410.4
Total Organic Carbon	EPA 415.1
Dissolved Organic Carbon	EPA 415.1
Aerobic microbial count	Laboratory Methods

B.6 SAMPLING, ANALYTICAL, AND QUALITY ASSURANCE PROCEDURES

General sampling, analytical, and quality assurance (QA) protocols for investigation activities at the Site are established in the Site Quality Assurance Project Plan (QAPP) (HLA, 1999). Specific procedures for the investigation activities proposed in this Plan are introduced in the subsections below.

Field investigation activities, environmental sampling, and sample handling will be performed and documented by the HLA project team and/or its subcontractors according to the detailed procedures in the HLA field manual. Laboratory sample analyses will be performed by Environmental Chemistry Services, Inc. (laboratory), of Englewood, Colorado.

B.6.1 Laboratory Analytical Procedures

The laboratory analytical program in support of the field investigation activities will characterize groundwater samples for target analytes. Groundwater samples will also be analyzed for general water quality parameters, as necessary. Table B.2 presents the target constituents, and the anticipated analytical methods and MRLs to be applied by the laboratory for the analysis of soil and water samples. The analytical methods referenced in Table B.2 are standard EPA methods from EPA-SW-846 (EPA, 1996b), "Methods for the Analysis of Water and Wastes" (EPA, 1983), and the American Society for Testing and Materials (ASTM). The program laboratory has developed and maintains a set of written instructions, or Standard Operating Procedures (SOPs), for performance of the reference methods.

B.6.2 Method Detection Limits and Method Reporting Limits

For organic analytes and applicable inorganic analytes, the MRLs reported by the laboratory will be supported by statistical method detection limit (MDL) studies performed in accordance with 40 CFR, Part 136, Appendix B. Analytical results for this compound will be reported to the MDL.

MRLs for target analytes may be sample-specific for samples with complex sample matrices (i.e., samples containing one or more analytes at widely varying concentrations) or samples containing interferences. In these cases, MRLs will increase if a sample has to be diluted to provide on-scale instrument response for high-concentration analytes. For high-level or complex samples that require lower MRLs, reanalysis will be performed by the laboratory upon approval of HLA. Samples that require lower detection limits will be identified before analyses, if possible, and the laboratory will be notified. Initial laboratory screening analysis may also assist the laboratory in identifying complex sample matrices and appropriate corrective actions before these samples undergo more rigorous analysis. Additional sample analyses, alternate analytical methods, and/or additional sample cleanup steps may be applied as necessary to minimize MRLs.

B.6.3 Sample Preservation, Containers, and Holding Times

Sample preservation, container, and holding time requirements have been identified and are summarized in Table B.3. Sample bottles, containers, and preservatives will be supplied by the program laboratory. The sample bottles and containers will be free of target analytes and of known quality (i.e., I-Chem 200 series or equivalent), as documented by the container manufacturer. Liners used to collect soil samples, if necessary, will be new and will be cleaned prior to use.

B.6.4 Quality Control Checks

External (field) and internal (laboratory) quality control (QC) samples will be used to monitor and quantify performance of analytical methods and field procedures. External QC samples are samples introduced into the sample train in the field to monitor data quality as a whole for the field investigation (i.e., the combined effects on the reported results of sample collection activities, shipping, and analysis). Internal QC samples are samples introduced into the sample train by laboratory personnel to monitor potential laboratory-induced contamination and analytical method performance.

B.6.4.1 External Quality Control

External QC samples collected in the field during the sampling programs will include the following:

- Field matrix duplicate samples (replicate samples)

Field duplicates will be submitted blind to the analytical laboratory during groundwater sampling activities.

B.6.4.2 Internal Quality Control

Laboratory internal QC checks represent internal system checks and controlled samples introduced by the laboratory into the sample analysis stream to monitor day-to-day variations in routine laboratory analyses. These checks are used to validate the data and assess the accuracy and precision of the chemical analysis program.

The method-specific SOPs developed by the laboratory identify the types of QC checks required, the frequency of each QC analysis, the analytes and reference concentrations to be used as controls, and the QC acceptance criteria. If, during the course of the sampling activities, the level of internal QC is assessed to be insufficient to meet data quality objectives, the laboratory may be required to revise its SOPs to incorporate additional QC checks and/or higher QC check frequencies. The general types of internal QC checks to be introduced by the laboratory are summarized below:

- Matrix spike/matrix spike duplicate (MS/MSD) samples
- Method blanks (preparation blanks)
- Instrument blanks
- Internal (matrix) duplicates
- Blank spikes (laboratory control samples)
- Surrogate spikes

- Internal standards
- Calibration standards

B.6.5 Data Review and Validation

Data collected during implementation of this Plan will be managed, distributed, and preserved to substantiate and document that the data are of known quality and are properly maintained. Field records and technical measurements will be reviewed and validated by HLA according to internal quality assurance (QA) procedures to monitor the performance of each task. Analytical data will be validated internally by the laboratory according to method-specific SOPs and laboratory QA protocols. HLA will not evaluate the analytical data quality based on the requirements of the reference analytical methods, laboratory SOPs, and, where applicable, the "USEPA Contract Laboratory Program National Functional Guidelines for Organic/Inorganic Data Review" (EPA, 1994a; 1994b). Standard EPA qualifiers will be applied by the laboratory to the analytical data to appraise data users of potential data use limitations.

B.7 DATA MANAGEMENT

Observations and measurements will be made in the field by HLA and by the subcontract analytical laboratory. The procedures described in this section will ensure that these data are properly documented and archived. Additionally, this section discusses the electronic database that shall contain pertinent data to facilitate retrieval.

B.7.1 Field Records

Field records generated during the program will include field notes, chain-of-custody records and sample labels, field boring logs, field sampling data sheets (FSDSs), daily field activity reports, and other forms and notes documenting field activities and observations. The Site supervisor shall review on a daily basis the chain-of-custody records, field notes, and FSDSs, boring logs, etc., for errors and omissions. The following sections discuss specific procedures for completing field logbooks and making corrections to field records.

B.7.1.1 Field Notes

Data collection activities performed onsite will be documented in field notes. Field notes shall be generated by field personnel during each activity and shall remain in the custody of field personnel during sampling activities. A project-specific identification number shall identify each set of field notes, which shall contain the following information:

- Name of the project
- Name of organization
- Start date
- End date

At the beginning of each day, the date, start time, weather, field personnel present, level of personal protective equipment (PPE) being used, and name of the person making the entry shall be recorded. The

names of subcontractors and visitors and the purpose of their visit shall also be recorded. Information pertinent to field activities shall be recorded in the field notes. Entries shall include at least the following:

- Name and title of author, date and time of entry, and physical/environmental conditions during field activity
- Location of sampling or field activity
- Nature of the field activity
- Name(s) and title(s) of field crew
- Name(s), organization(s). and title(s) of subcontractors
- Name(s), organization(s), and title(s) of site visitors and purpose of visits
- Type of media sampled or measured
- Sample collection or measurement method
- Number and volume of samples(s) collected
- Description of measuring reference points
- Date and time of sample collection
- Sample identification numbers(s)
- Sample preservative, if applicable
- Sample distribution (e.g., laboratory)
- Locations of sampling points
- References for maps and photographs of the sampling site(s)
- Field observations and comments
- Field measurements recorded (e.g., PID reading)
- Sample documentation including dates and methods of sample shipment

B.7.1.2 Corrections to Documentation

Unless prohibited by weather conditions, data recorded in field notes, field forms, sample labels, and COC records shall be completed in black or blue waterproof ink. Accountable, serialized documents shall not be destroyed or discarded, even if the documents are illegible or contain inaccuracies that require a replacement document. Unused serialized documents, such as chain-of-custody records, may be destroyed at the completion of a field program. If any information has been recorded on these documents, it shall not be destroyed.

Errors on field documents shall be corrected by drawing a single line through the error and entering the correct information. The person who made the original entry should correct errors on a field document, and the erroneous information should not be obliterated. Corrections shall be initialed and dated.

B.7.2 Laboratory Deliverables

Deliverables from subcontract laboratories will include raw and summarized analytical data. Subcontract laboratories shall submit analytical data under a cover letter or case narrative that describes the samples processed, unusual circumstances or problems encountered during sample analysis, and corrective actions. Subcontract laboratories shall submit electronic copies of reduced data whenever possible, for upload to the project databases. The format for electronic deliverables from subcontract laboratories shall be approved by HLA, but shall include, at a minimum, the following information:

- HLA sample identification
- Sample date
- Laboratory sample identification
- Laboratory case, job, or sample delivery group identification
- Method of analysis
- Extraction date (as required)

- Analysis date
- Analyte
- Result or practical quantitation limit
- Laboratory applied qualifiers
- Units of measure

Hardcopy raw and summarized data packages shall be submitted to the file custodian as described in Section B.7.5. Electronic deliverables shall be supplied to the Project Data Manager for processing and upload to the project database as described in Section B.7.4.

B.7.3 Subcontractor Deliverables

Deliverables from subcontractors other than laboratories will include Site information, such as survey data. Subcontractors shall submit data under a cover letter that describes the data and pertinent information and references required to collect the information. Subcontractors shall submit electronic copies of reduced data whenever possible, for uploading to the project databases. The format for electronic deliverables from subcontractors shall be approved by HLA.

Hardcopy data shall be submitted to the file custodian as described in Section B.7.5. Electronic deliverables shall be supplied to the Project Data Manager for processing and uploading to the project database as described in Section B.7.4.

B.7.4 Project Database

HLA shall maintain a project database to allow easy access to Site information. The database will contain data that are conducive to storage in a tabular database that may include analytical, survey, water-level, well construction, and soil boring data. The Project Data Manager shall be responsible for ensuring pertinent data collected at the site are entered into the database and that the data included in the database match the hardcopy documentation provided. Electronic deliverables received from subcontractors shall

be processed and loaded into the database. Five percent of the data received electronically shall be checked against hardcopy data to ensure consistency. If errors are found, a larger percentage of data in the database shall be reviewed against the hardcopy data. Information not provided electronically shall be hand entered and every value in the database checked against the hardcopy data. Reports produced from the database shall be reviewed by technical personnel (e.g., chemist, geologist) to ensure the validity and accuracy of the information being reported.

B.7.5 Final File Procedures

HLA is the custodian of the final project file and maintains the contents of project files. HLA will maintain the project files along with relevant records, reports, logs, field notes, photographs, subcontractor reports, laboratory data, and reviews of the laboratory data under document control in a limited access secure area under custody of the HLA Quality Assurance Manager or designated file custodian. The final project file will contain, at a minimum, the following project data:

- Planning documents
- Field data records
- Field notes
- Completed chain-of-custody records
- Photographs, maps, and drawings
- Final reports
- Laboratory analytical result reports and raw data packages

Documents shall be provided to the file custodian for cataloguing and filing. Access to the project file shall be controlled and documents removed from the file area shall be checked out to the requesting party.

Table B1: Baseline and Operational Groundwater Monitoring
CDOT - Region 6 Headquarters Site
CDOT Project No. CC010-053, Sub-account 12513

	Baseline				Months 1 to 3				Months 4 to 6			
Well ID	Water Level	Field Parameters (1)	Chemical/ Biological Indicators (2)	VOCs/ Nutrients (3)	Water Level	Field Parameters (1)	Chemical/ Biological Indicators (2)	VOCs/ Nutrients (3)	Water Level	Field Parameters (1)	Chemical/ Biological Indicators (2)	VOCs/ Nutrients (3)
Lower Zone												
C-MW30B	O	O	O	O	W	W	BW	BW	SM	SM	M	M
C-MW20D	O	O	O	O	W	W	BW	BW	SM	SM	M	M
	Total Samples:		**2**	**2**			**12**	**12**			**6**	**6**
Upper Zone												
C-MW20S	O	O	O	O	W	W	BW	BW	SM	SM	M	M
C-MW29A	O	O	O	O	W	W	BW	BW	SM	SM	M	SM
	Total Samples:		**2**	**2**			**12**	**12**			**6**	**9**

O - Once
W - Weekly
BW - Bi-weekly
SM - Semi-monthly
M - Monthly

1. Field parameters include the following:
   - pH
   - Conductivity
   - Oxidation/Reduction Potential
   - Dissolved Oxygen
   - Temperature

2. Chemical/Biological indicators include the following:
   - Methane
   - Sulfate
   - Chloride
   - Alkalinity to pH 8.3
   - Alkalinity to pH 4.5
   - Carbon Dioxide (Hach Field Kit)
   - Chemical Oxygen Demand
   - Total Organic Carbon
   - Dissolved Organic Carbon
   - Aerobic Microbial Count

3. VOCs/Nutrients include the following:
   - VOCs - 8260B
   - Phosphate (Hach Field Kit)
   - Nitrate as Nitrogen
   - Ammonia

Table B.2: Target Analytes and Method Reporting Limits

Analyte Name	Minimum Method Reporting Limit* Aqueous
Volatile Organic Compounds (µg/l)	
1,1,1,2-Tetrachloroethane	5
1,1,1-Trichloroethane	5
1,1,2,2-Tetrachloroethane	5
1,1,2-Trichloroethane	5
1,1-Dichloroethane	5
1,1-Dichloroethene	5
1,1-Dichloropropene	5
1,2,3-Trichlorobenzene	5
1,2,3-Trichloropropane	5
1,2,4-Trichlorobenzene	5
1,2,4-Trimethylbenzene	5
1,2-Dibromo-3-chloropropane	5
1,2-Dibromoethane	5
1,2-Dichlorobenzene	5
1,2-Dichloroethane	5
1,2-Dichloropropane	5
1,2-Dimethylbenzene (o-Xylene)	5
1,3,5-Trimethylbenzene	5
1,3-Dichlorobenzene	5
1,3-Dichloropropane	5
1,3/1,4-Dimethylbenzene (m,p-Xylenes)	5
1,4-Dichlorobenzene	5
2,2-Dichloropropane	5
2-Butanone	5
2-Chloroethyl vinyl ether	5
2-Chlorotoluene	5
2-Hexanone	5
2-Methoxy-2-methylpropane	5
2-Phenylbutane (sec-Butylbenzene)	5
4-Chlorotoluene	5
4-Isopropyltoluene	5
4-Methyl-2-pentanone	5
Acetone	5
Acrylonitrile	5
Benzene	5
Bromobenzene	5
Bromochloromethane	5
Bromodichloromethane	5
Bromoform	5

Table B.2 (continued)

Analyte Name	Minimum Method Reporting Limit* Aqueous
Bromomethane	5
Butylbenzene	5
Carbon disulfide	5
Carbon tetrachloride	5
Chloroethane	5
Chloroform	5
Chloromethane	5
cis-1,2-Dichloroethene	5
cis-1,3-Dichloropropene	5
Dibromochloromethane	5
Dibromomethane	5
Dichlorodifluoromethane	5
Ethylbenzene	5
Hexachlorobutadiene	5
Iodomethane	5
Isopropylbenzene	5
Methylene chloride	5
Naphthalene	5
Propylbenzene	5
Styrene	5
tert-Butylbenzene	5
Tetrachloroethene	5
Toluene	5
trans-1,2-Dichloroethene	5
trans-1,3-Dichloropropene	5
trans-1,4-Dichloro-2-butene	5
Trichloroethene	5
Trichlorofluoromethane	5
Trichlorotrifluoroethane	5
Vinyl acetate	5
Vinyl chloride	5
Methane (µg/l)	10
Nitrate as Nitrogen (mg/l)	0.1
Ammonia (mg/l)	0.2
Sulfate (mg/l)	0.5
Chloride (mg/l)	0.5
Residual Chlorine (mg/l)	0.05
Alkalinity to pH 8.3 (mg/l)	5
Alkalinity to pH 4.5 (mg/l)	5
Chemical oxygen demand (mg/l)	5
Total organic carbon (mg/l)	1

Table B.2 (continued)

Analyte Name	Minimum Method Reporting Limit* Aqueous
Dissolved organic carbon (mg/l)	1
Aerobic microbial count (CFU)	1

µg/l	Micrograms per liter
CFU	Colony forming unit
mg/l	Milligrams per liter
EPA	U.S. Environmental Protection Agency

* Reporting limits are matrix dependent, and listed limits may not always be achievable. Actual limits attained will be reported by the laboratory.

Table B.3: Summary of Sample Containers, Preservation Requirements, and Holding Times

Analysis	Container	Preservative	Holding Time
Aqueous Samples			
Volatile Organic Compounds	Three 40-ml VOA vials	HCl, pH < 2, Cool 4°C	14 days to analysis
Methane	Two 40-ml VOA vials	Cool 4°C	7 days
Nitrate as Nitrogen	One 250-ml plastic bottle	Cool 4°C	48 hours
Ammonia	One 1-L plastic bottle	H_2SO_4, pH < 2, Cool 4°C	28 days
Sulfate	One 125-ml plastic bottle	Cool 4°C	28 days
Chloride	One 125-ml plastic bottle	Cool 4°C	28 days
Residual Chlorine	One 500-ml plastic bottle	Cool 4°C	analyze immediately
Alkalinity to pH 8.3	One 250-ml plastic bottle	Cool 4°C	14 days
Alkalinity to pH 4.5	One 250-ml plastic bottle	Cool 4°C	14 days
Chemical Oxygen Demand	One 125-ml plastic bottle	H_2SO_4, pH < 2, Cool 4°C	28 days
Total Organic Carbon	Two 40-ml VOA vials	H_2SO_4, pH < 2, Cool 4°C	28 days
Dissolved Organic Carbon	Two 40-ml VOA vials	H_2SO_4, pH < 2, Cool 4°C	28 days
Aerobic microbial count	One 1-L plastic bottle	Cool 4°C	28 days

When multiple methods of analysis are requested for a sample, more than one method may be collected in a single container while providing the laboratory sufficient volume for analysis. Therefore, the HLA Program QA/QC Chemist should contact the laboratory prior to sample collection to verify the containers required.

°C Degrees Centigrade
L Liter
ml Milliliter
VOA Volatile organic analysis

Summary of Groundwater Analytical Results

	Site	C-MW16S	C-MW17D
	Date	1/6/99	1/7/99
Metals (mg/l)			
Aluminum		3.23	53.6
Antimony		0.002 U	0.002 UJ
Arsenic		0.006 J	0.012
Barium		0.077	0.527
Beryllium		0.0004 J	0.0021
Cadmium		0.002 U	0.002 U
Calcium		365	192
Calcium, dissolved		378	183
Chromium		0.0038	0.0249
Cobalt		0.0074	0.0126
Copper		0.007 J	0.034
Iron		2.68	40.7
Lead		0.0015 J	0.0169
Magnesium		28.2	18.9
Magnesium, dissolved		29.3	11.7
Manganese		1.94	0.654
Mercury		0.001 U	0.001 U
Nickel		0.017	0.017
Potassium		3.4	6.1
Selenium		0.018	0.015
Silver		0.0002 J	0.0006 J
Sodium		601	438
Thallium		0.001 U	0.0004 J
Vanadium		0.06 U	0.103
Zinc		0.1 U	0.11
Wet Chemistry (mg/l)			
Alkalinity (as CaCO3)		385	429
Alkalinity, bicarbonate		385	429
Calculated hardness		1,070	506
Nitrate as nitrogen		16.1	15.7
Nitrite as nitrogen		1.8	0.16
Sulfate		1,310	780
Total dissolved solids		3,130	1,960

Summary of Groundwater Analytical Results: wells near and upgradient of source area

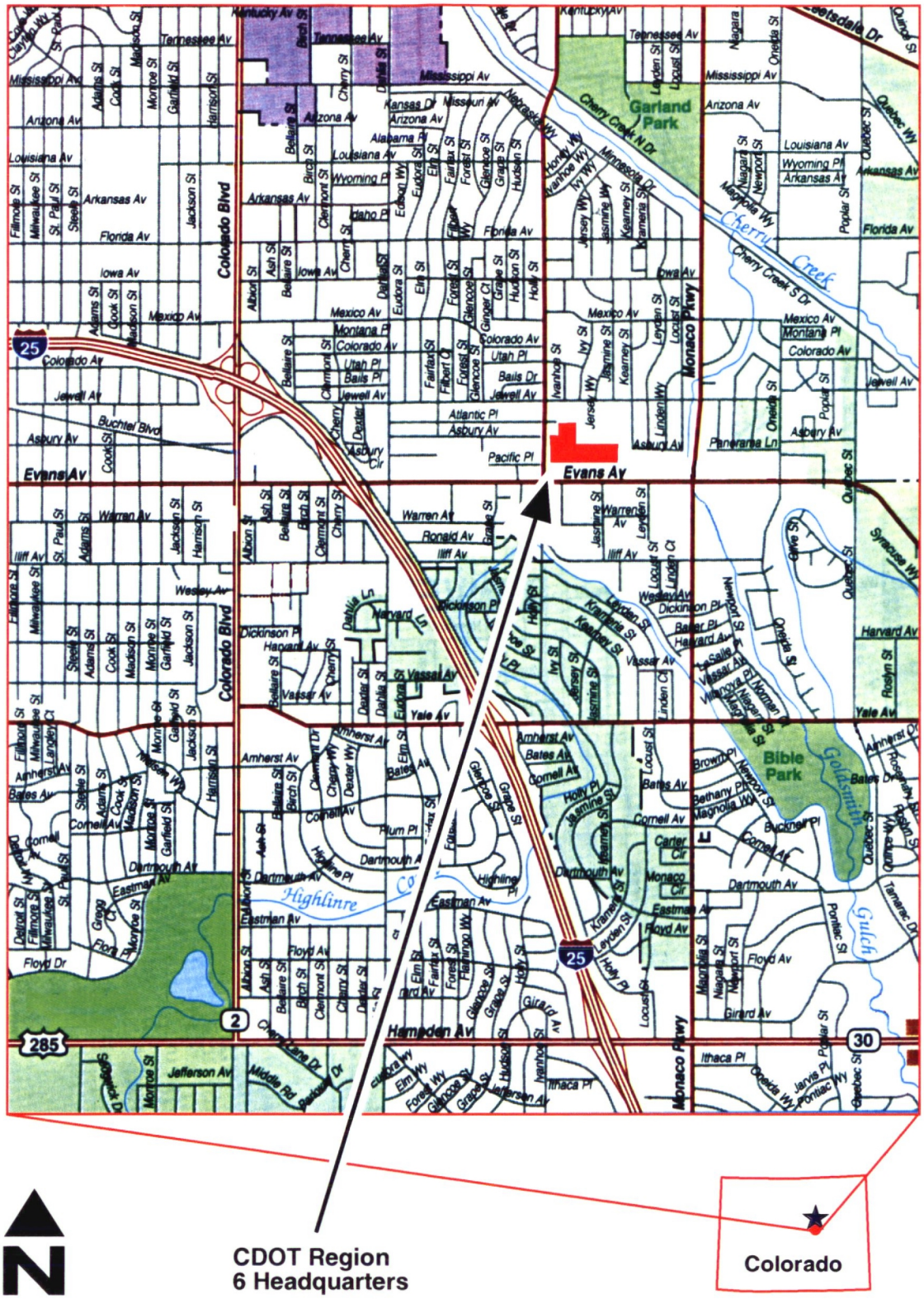
	Wells Near Source						
Well ID	C-MW20D	C-MW20D	C-MW20S	C-MW20S	C-MW11	C-MW11	C-MW11
Sample Date	3/18/99	6/10/99	3/18/99	6/10/99	12/15/98	1/6/99	3/17/99
Well Depth	52.7'	52.7'	32.5'	32.5'	40.0'	40.0'	40.0'
Compound (µg/l)							
Dichlorodifluoromethane	10 U	10 U	10 U	10 U	100,000 UJ	500 UJ	10 U
Chloromethane	10 U	10 U	10 U	10 U	200,000 UJ	1,000 U	10 U
Vinyl chloride	10 U	10 U	**4 J**	**5 J**	200,000 UJ	1,000 U	**4 J**
Bromomethane	10 UJ	10 U	10 U	10 U	200,000 UJ	1,000 UJ	10 U
Chloroethane	10 U	10 U	10 U	10 U	200,000 UJ	1,000 U	10 U
Trichlorofluoromethane	10 UJ	10 U	10 UJ	10 U	100,000 UJ	500 U	10 UJ
1,1-Dichloroethene	5 U	5 U	**94**	**110**	100,000 UJ	**330 J**	**160**
Acetone	100 U	10 U	100 U	10 U	200,000 UJ	1,000 U	100 U
Iodomethane	50 UJ	10 U	50 UJ	10 U	NA	NA	50 UJ
Carbon disulfide	5 U	5 U	5 U	5 U	100,000 UJ	500 U	**7.9**
Methylene chloride	**180**	**52 J**	**530,000**	**510,000 J**	**1,300,000 J**	**2,200,000 J**	**850,000**
trans-1,2-Dichloroethene	5 U	5 U	**100**	**70**	100,000 UJ	**360 J**	**160**
2-Methoxy-2-methylpropane	**1 J**	5 U	5 U	5 U	NA	NA	5 U
1,1-Dichloroethane	5 U	5 U	**4 J**	**5 J**	100,000 UJ	500 UJ	**11**
Vinyl acetate	50 U	10 U	50 U	10 U	NA	NA	50 U
2,2-Dichloropropane	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
cis-1,2-Dichloroethene	5 U	5 U	**15**	**8.1**	100,000 UJ	500 UJ	**32**
2-Butanone	50 U	10 U	50 U	10 U	200,000 UJ	1,000 UJ	50 U
Bromochloromethane	5 U	5 U	**7.2**	**4 J**	100,000 UJ	500 UJ	**5.5**
Chloroform	5 U	5 U	**19**	**14**	100,000 UJ	500 U	**31**
1,1,1-Trichloroethane	5 UJ	5 U	**9.9**	**12**	100,000 UJ	500 U	**9.1**
1,1-Dichloropropene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Carbon tetrachloride	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Benzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,2-Dichloroethane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
Trichloroethene	5 U	5 U	**410**	**320**	100,000 UJ	**1,000**	**570**
1,2-Dichloropropane	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Dibromomethane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
Bromodichloromethane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
2-Chloroethyl vinyl ether	5 U	10 U	5 U	10 U	NA	NA	5 U
cis-1,3-Dichloropropene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
4-Methyl-2-pentanone	50 U	10 U	50 U	10 U	200,000 UJ	1,000 UJ	50 U
Toluene	5 U	5 U	**3 J**	**2 J**	100,000 UJ	500 U	**5 J**
trans-1,3-Dichloropropene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,1,2-Trichloroethane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
1,2-Dibromoethane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
Tetrachloroethene	5 U	5 U	**200**	**230**	100,000 UJ	**500**	**300**
1,3-Dichloropropane	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
2-Hexanone	50 U	10 U	50 U	10 U	200,000 UJ	1,000 UJ	50 U
Dibromochloromethane	5 U	5 UJ	5 U	5 U	100,000 UJ	500 U	5 U
Chlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,1,1,2-Tetrachloroethane	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Ethylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
m,p-Xylenes	5 U	5 U	5 U	5 U	NA	NA	5 U

Summary of Groundwater Analytical Results: wells near and upgradient of source area

	Wells Near Source						
Well ID	C-MW20D	C-MW20D	C-MW20S	C-MW20S	C-MW11	C-MW11	C-MW11
Sample Date	3/18/99	6/10/99	3/18/99	6/10/99	12/15/98	1/6/99	3/17/99
Well Depth	52.7'	52.7'	32.5'	32.5'	40.0'	40.0'	40.0'
Compound (µg/l)							
o-Xylene	5 U	5 U	5 U	5 U	NA	NA	5 U
Styrene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Bromoform	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Isopropylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Bromobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,1,2,2-Tetrachloroethane	5 U	5 U	5 UJ	5 U	100,000 UJ	500 UJ	5 U
1,2,3-Trichloropropane	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Propylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
2-Chlorotoluene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
4-Chlorotoluene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,3,5-Trimethylbenzene	5 U	5 U	**1 J**	5 U	100,000 UJ	500 U	**1 J**
tert-Butylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,2,4-Trimethylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	**4 J**
sec-Butylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,3-Dichlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
4-Isopropyltoluene	5 U	5 U	**4 J**	5 U	100,000 UJ	500 U	5 U
1,4-Dichlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,2-Dichlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Butylbenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
1,2-Dibromo-3-chloropropane	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
1,2,4-Trichlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Hexachlorobutadiene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U
Naphthalene	5 U	5 U	5 U	5 U	100,000 UJ	500 UJ	5 U
1,2,3-Trichlorobenzene	5 U	5 U	5 U	5 U	100,000 UJ	500 U	5 U

ATTACHMENT C

SITE MAPS



Harding Lawson Associates
Engineering and
Environmental Services

Site Location Map
CDOT Region 6 Headquarters

Denver, Colorado

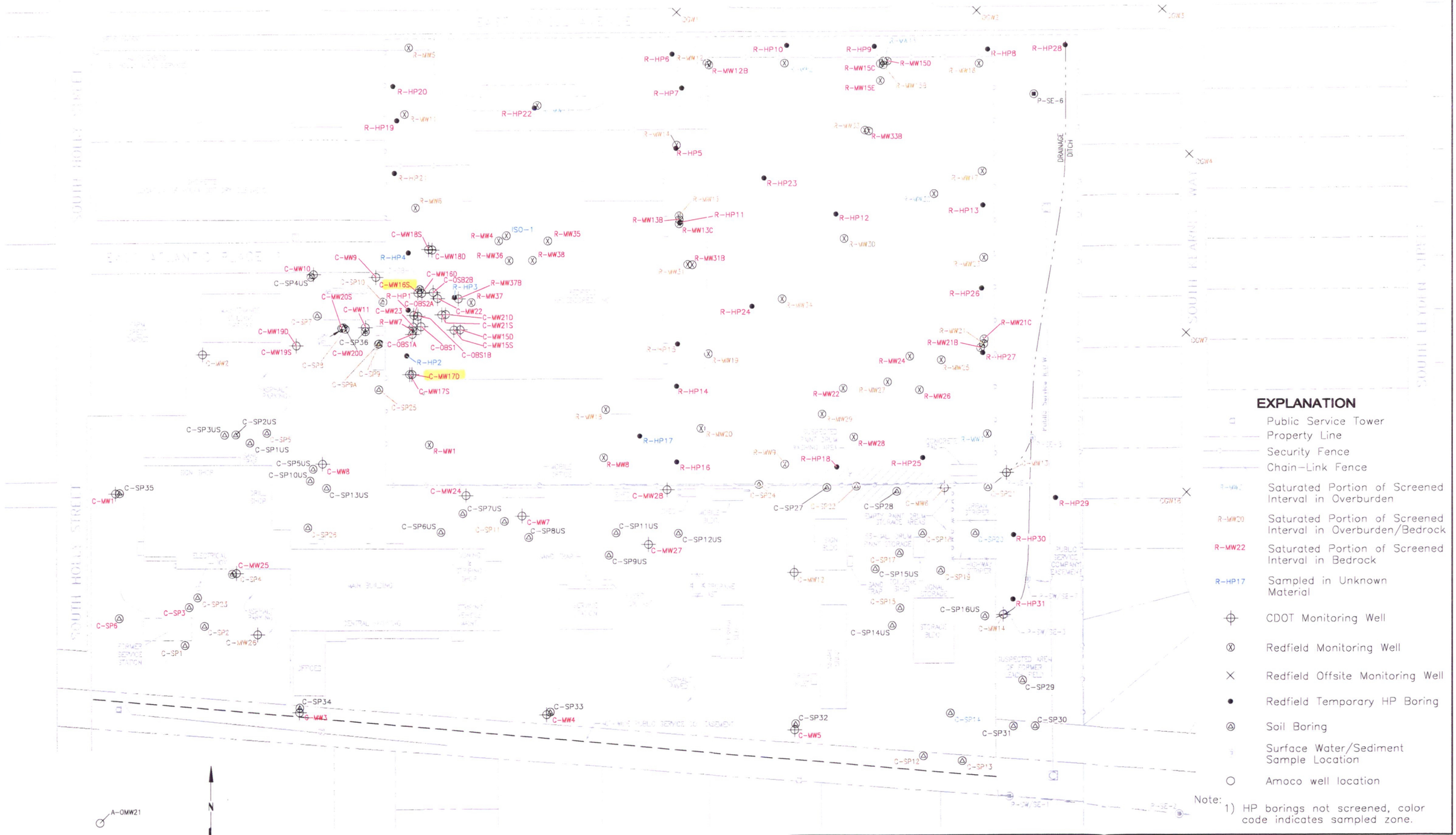
FIGURE
1

DRAWN	JOB NUMBER	APPROVED	DAT	REVISED DATE
NLM	42708		11/98	

Appendix A

DRAWINGS

42708/CAD/42708050 9/3/99 LDZ



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW: Saturated Portion of Screened Interval in Overburden
- R-MW20: Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22: Saturated Portion of Screened Interval in Bedrock
- R-HP17: Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- Redfield Temporary HP Boring
- Soil Boring
- Surface Water/Sediment Sample Location
- Amoco well location

Note:
1) HP borings not screened, color code indicates sampled zone.

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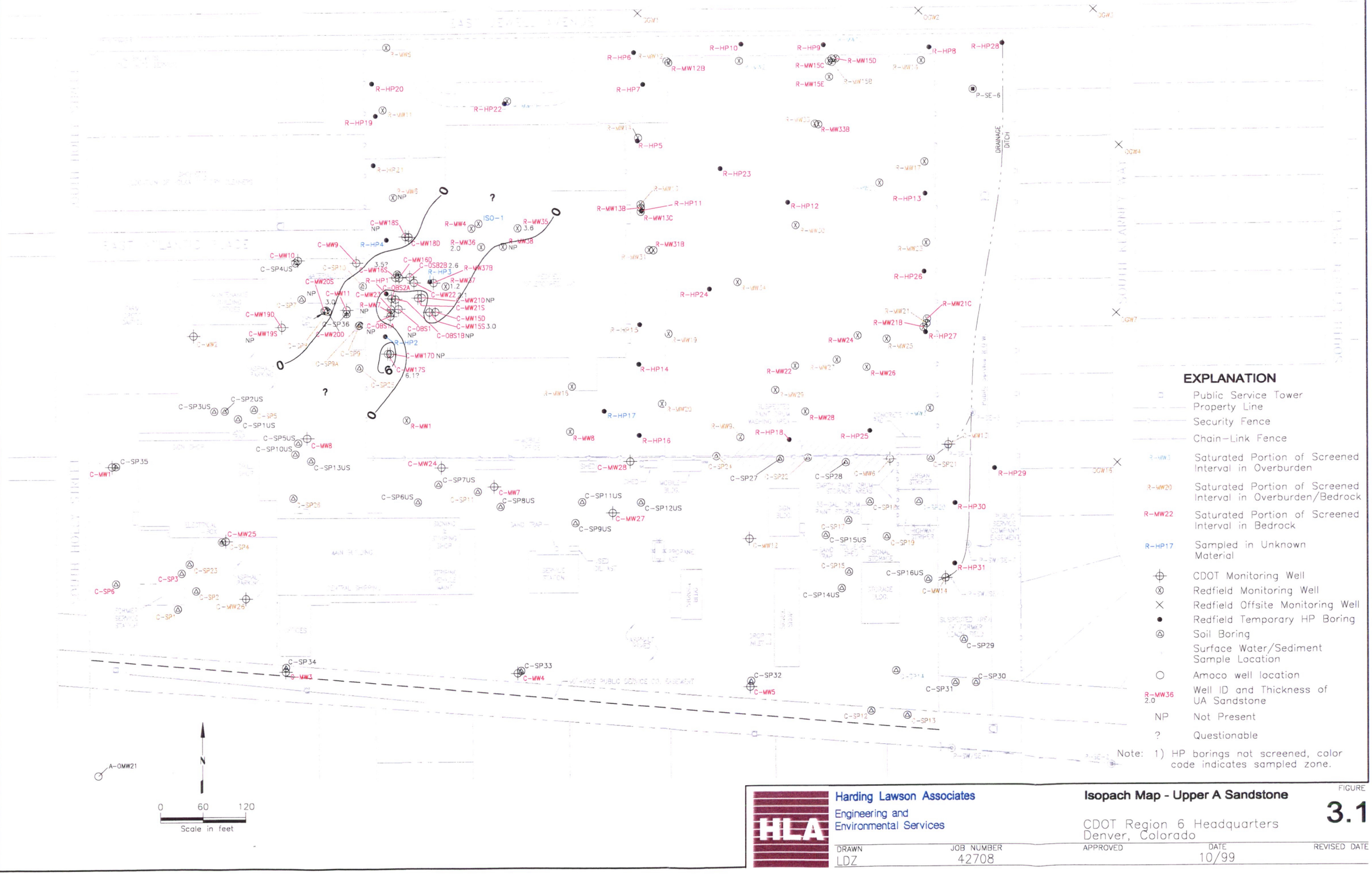
Base Map

CDOT Region 6 Headquarters
Denver, Colorado

FIGURE 2.1

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		9/99	

42708/CAD/42708059 10/20/99 LDZ



Harding Lawson Associates
Engineering and Environmental Services

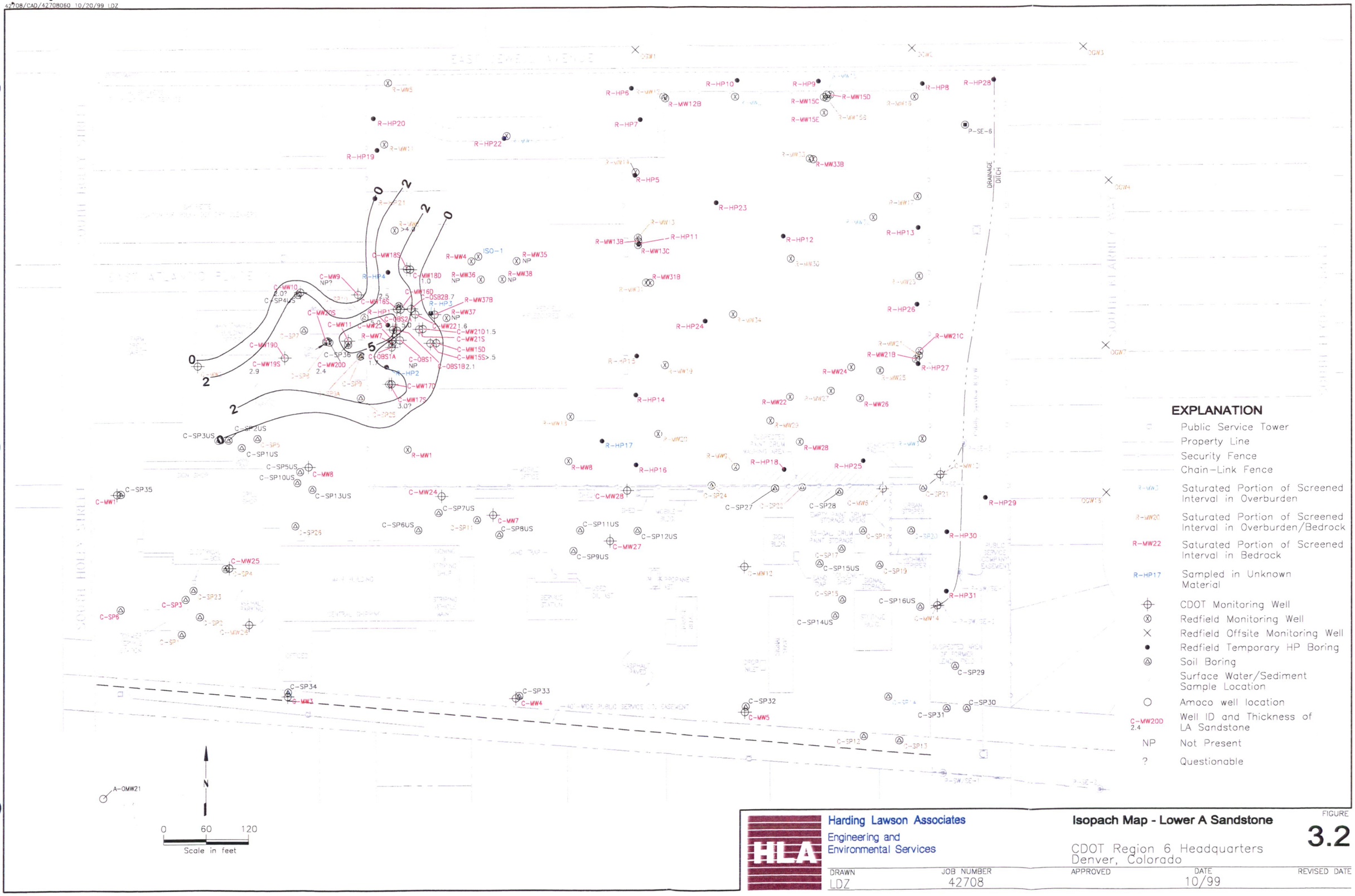
Isopach Map - Upper A Sandstone

CDOT Region 6 Headquarters
Denver, Colorado

FIGURE **3.1**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		10/99	

42708/CAD/42708060 10/20/99 LDZ



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW3 — Saturated Portion of Screened Interval in Overburden
- R-MW20 — Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22 — Saturated Portion of Screened Interval in Bedrock
- R-HP17 — Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- Redfield Temporary HP Boring
- Soil Boring
- Surface Water/Sediment Sample Location
- Amoco well location
- C-MW20D 2.4 — Well ID and Thickness of LA Sandstone
- NP — Not Present
- ? — Questionable

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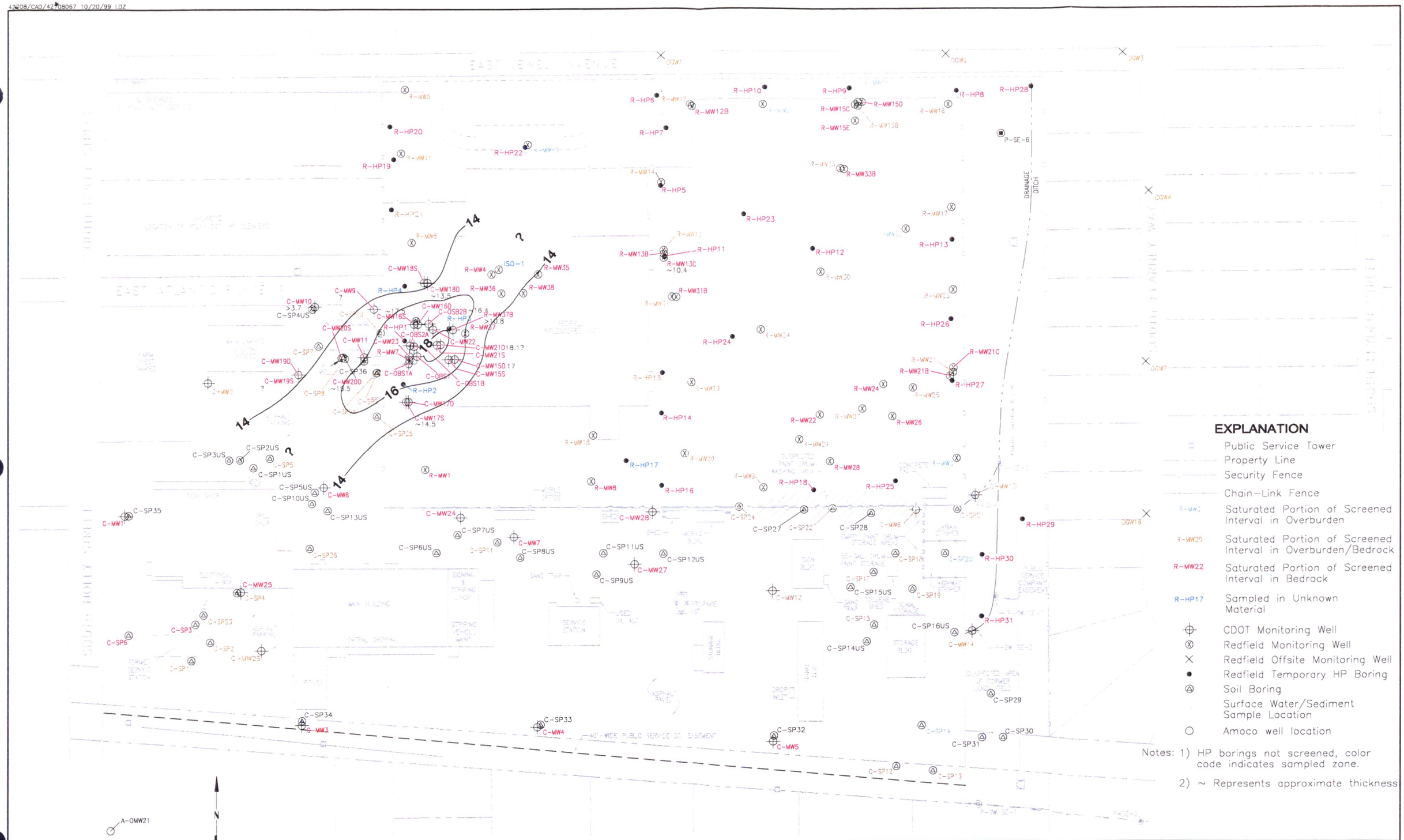
Isopach Map - Lower A Sandstone

CDOT Region 6 Headquarters
Denver, Colorado

FIGURE 3.2

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		10/99	

42708/CAD/42708067 10/20/99 LDZ



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW2 — Saturated Portion of Screened Interval in Overburden
- R-MW20 — Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22 — Saturated Portion of Screened Interval in Bedrock
- R-HP17 — Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- Redfield Temporary HP Boring
- Soil Boring
- Surface Water/Sediment Sample Location
- Amoco well location

Notes: 1) HP borings not screened, color code indicates sampled zone.

2) ~ Represents approximate thickness

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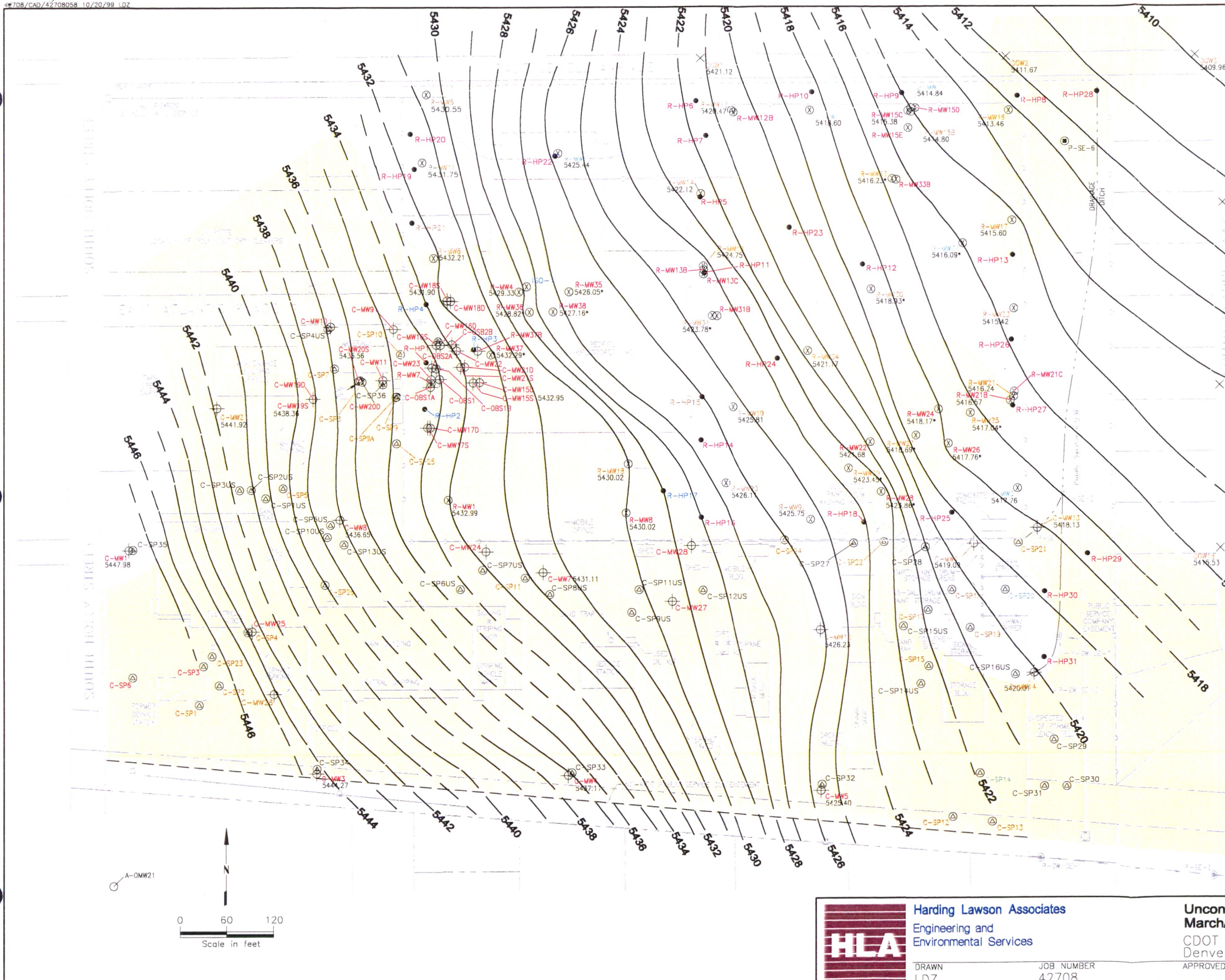
Isopach Map - Lower B Sandstone

CDOT Region 6 Headquarters
Denver, Colorado

FIGURE **3.4**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		10/99	



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW3 — Saturated Portion of Screened Interval in Overburden
- R-MW20 — Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22 — Saturated Portion of Screened Interval in Bedrock
- R-HP17 — Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- Redfield Temporary HP Boring
- Soil Boring
- Surface Water/Sediment Sample Location
- Amoco well location
- Approximate area of Unsaturated Overburden
- 5417.76• — Indicates groundwater elevation from 4/12/99

Notes: 1) HP borings not screened, color code indicates sampled zone.

2) If groundwater level not shown well is screened in potentially confined aquifer or water level not available.

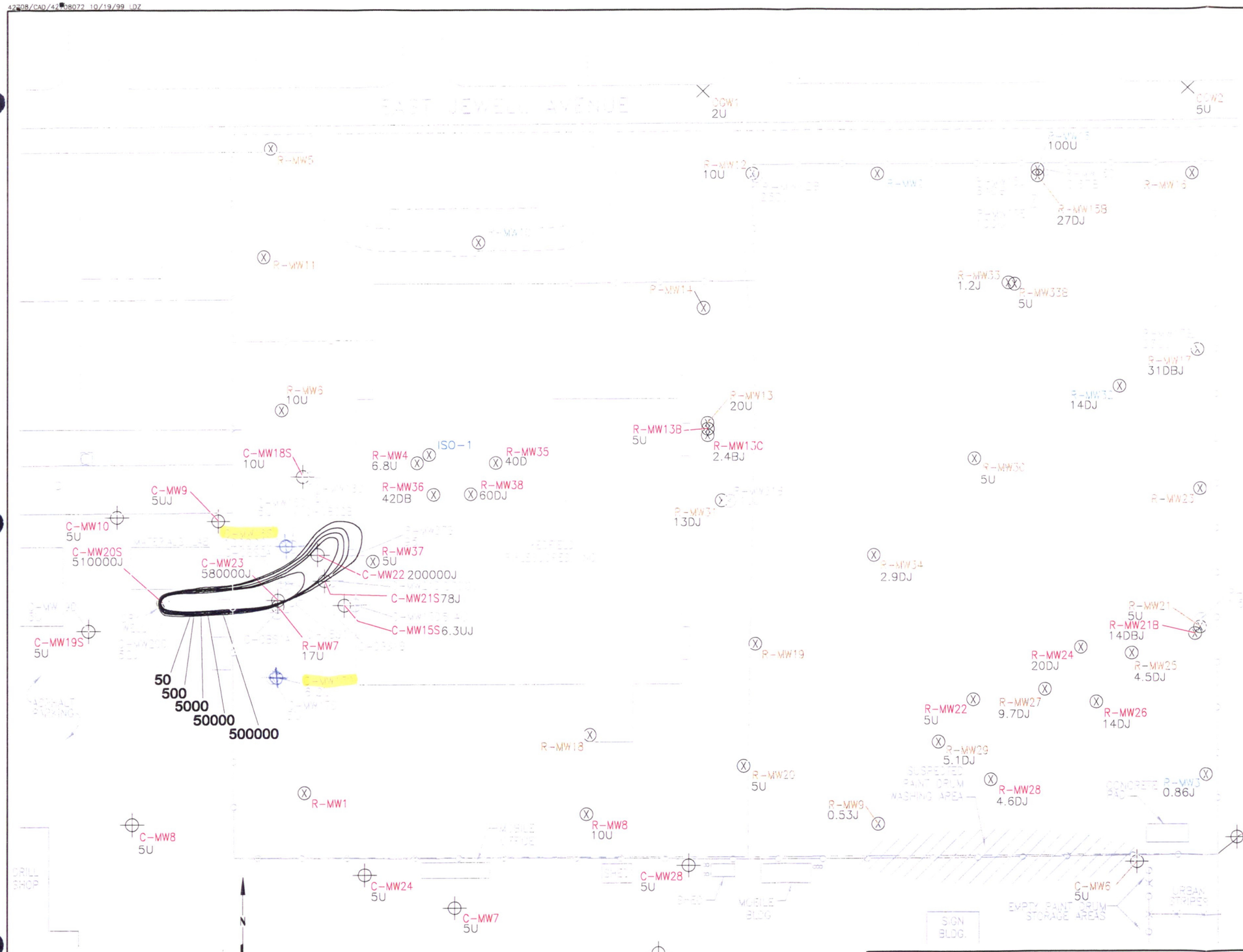
Harding Lawson Associates
Engineering and Environmental Services

Unconfined Groundwater Table Map March/April 1999

CDOT Region 6 Headquarters
Denver, Colorado

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE	FIGURE
LDZ	42708		10/99		4.1

42708/CAD/42708072 10/19/99 LDZ



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW7 — Saturated Portion of Screened Interval in Overburden
- R-MW20 — Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22 — Saturated Portion of Screened Interval in Bedrock
- R-HP17 — Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- C-MW4 5UJ — Well ID and reported Methylene Chloride concentration (ug/l)
- U — Not detected above the reporting limit
- J — Reported concentration is estimated
- D — Sample was diluted to meet instrument calibration criteria
- B — Compound was detected in method blank
- Methylene Chloride Concentration Contour

Note: 1) Reported concentrations are from June 1999 sampling event.

2) Except for R-MW4, R-MW7, and R-MW37, data reported for Redfield wells were obtained from Envirogroup.

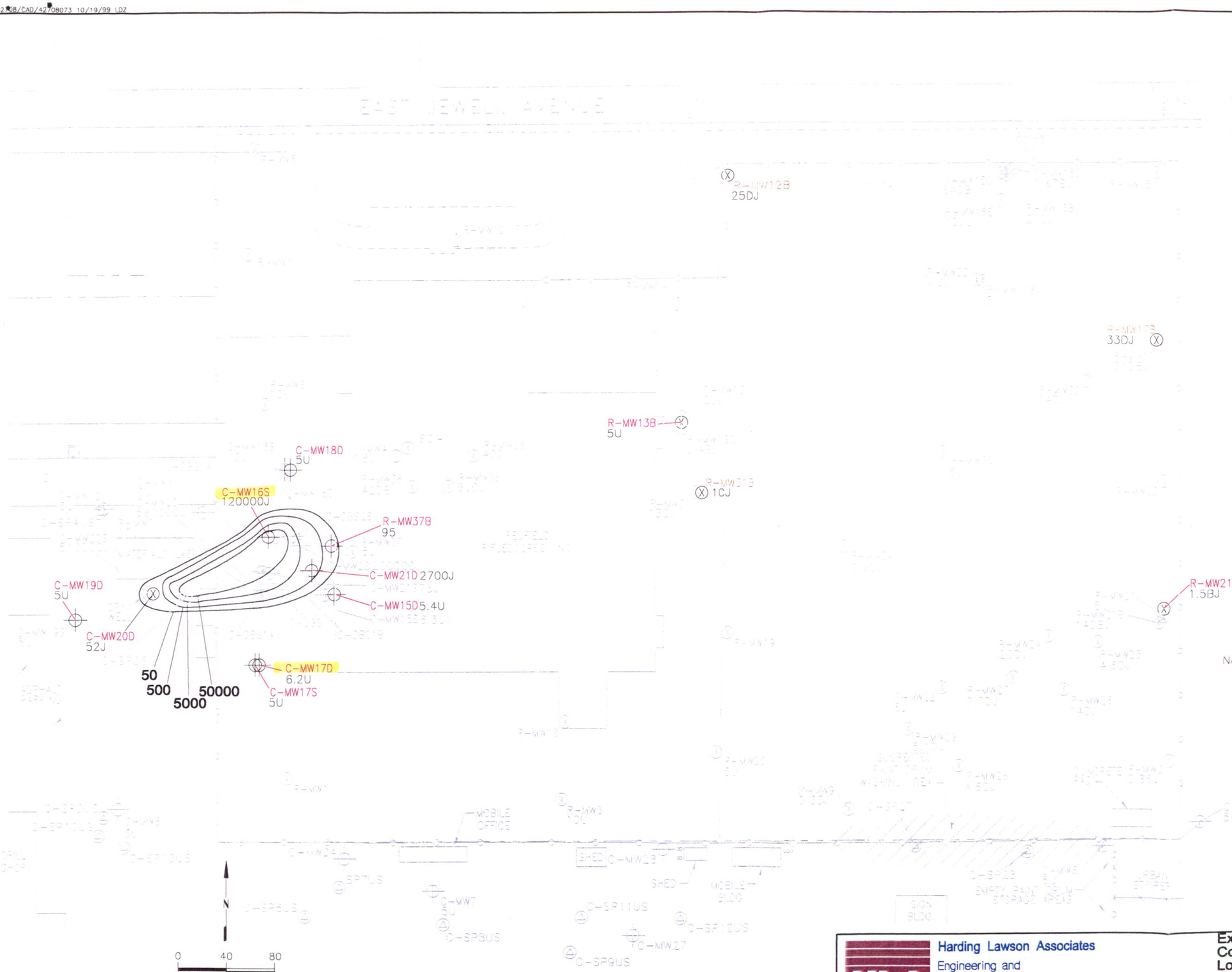
HLA

Harding Lawson Associates
Engineering and Environmental Services

Extent of Methylene Chloride Contamination for A Sandstone/ Upper Aquifer
CDOT Region 6 Headquarters
Denver, Colorado

FIGURE **5.1**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		9/99	



EXPLANATION

- Public Service Tower
- Property Line
- Security Fence
- Chain-Link Fence
- R-MW1 — Saturated Portion of Screened Interval in Overburden
- R-MW20 — Saturated Portion of Screened Interval in Overburden/Bedrock
- R-MW22 — Saturated Portion of Screened Interval in Bedrock
- R-HP17 — Sampled in Unknown Material
- CDOT Monitoring Well
- Redfield Monitoring Well
- Redfield Offsite Monitoring Well
- C-MW4 5UJ — Well ID and reported Methylene Chloride concentration (ug/l)
- U — Not detected above the reporting limit
- J — Reported concentration is estimated
- D — Sample was diluted to meet instrument calibration criteria
- B — Compound was detected in method blank
- Methylene Chloride Concentration Contour

Note: 1) Reported concentrations are from June 1999 sampling event

2) Except for R-MW4, R-MW7, and R-MW37, data reported for Redfield wells were obtained from Envirogroup.

Harding Lawson Associates
Engineering and Environmental Services

Extent of Methylene Chloride Contamination for B Sandstone/ Lower Aquifer
CDOT Region 6 Headquarters
Denver, Colorado

FIGURE **5.2**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
LDZ	42708		9/99	